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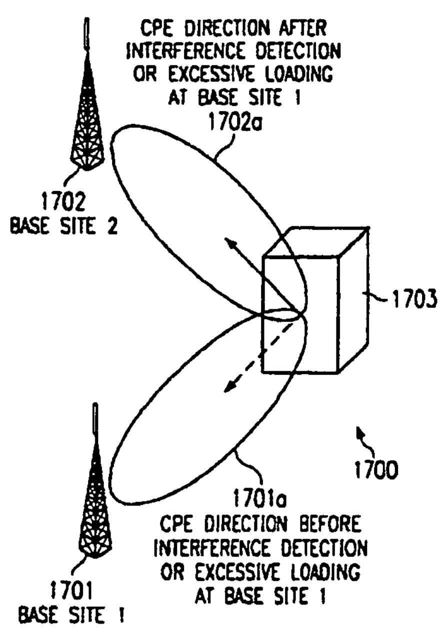

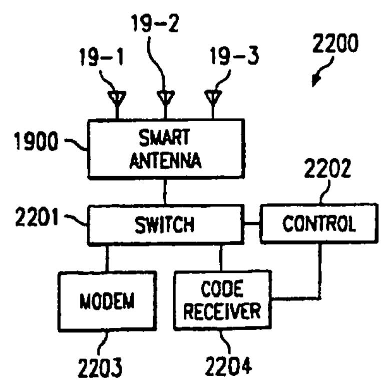

(57) Abstract: Systems and methods adapted to optimize data throughput in wireless communications network are shown and described. In the preferred embodiment a directionally controllable remove station is used. The antenna radiation pattern at the remote station is tailored from time to time to maximize transmission throughput. The remote station transmission pattern can be, for example, phased arrays, or could be narrow beam and mechanical adjustment. The transmission radiation pattern, if desired, could be directed to one base station which reception is from a different base station.

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REMOTE STATIONS WITH SMART ANTENNA SYSTEMS AND METHOD FOR CONTROLLING BEAM DIRECTIONS

RELATED APPLICATION

This application is a continuation-in-part of copending patent application entitled "High Speed Fixed Wireless Voice/Data Systems and Method, (P036US) filed October 19, 1999, serial number 09/422,210, which is hereby incorporated by reference herein.

REMOTE STATIONS WITH SMART ANTENNA SYSTEMS AND METHOD FOR CONTROLLING BEAM DIRECTIONS

TECHNICAL FIELD

The invention relates to wireless communication systems and more particularly to remote station antenna systems and methods useful in establishing wireless communication systems capable of providing high data bandwidth channels between the remote station and a plurality of base stations optimizing use of radio frequency spectrum, and even more particularly to such system and methods using directionally selected or formed antenna beams.

BACKGROUND

It is often desirable to utilize wireless radio links to provide information communication. The use of wireless links may be advantageous where wired infrastructure (e.g., copper and/or fibre communication network) is not in place to provide information communication or where user demand, whether the number of users and/or the capacity required by users, does not make it economical to provide wired infrastructure. For example wireless local loop (WLL) is often thought of to provide voice services in places where wireline service is not available, such as in less developed countries and remote areas within the United States.

In addition to providing voice services to remote sites not otherwise provided wireline service, it may also be desired to use radio to provide high rate data services to fixed users where wireline service is inadequate or not available. However, a problem with providing high rate data services, such as 1 MB/s, is that RF spectrum is limited and expensive. For example, to attain high peak rates often required or desired by data systems, spectrum bandwidth on the order of 1 MHZ is typically required. Spectrum in the 1-3 GHz range may be utilized to attain high peak rates such as 1 MB/s. Such frequencies may also be suitable for use in providing data system communication as their frequency propagation conditions typically allow partial line-of-sight or even non-line-of-sight between a base station (BS) and a remote station (RS), thus simplifying deployment of a network.

Although possibly providing suitable spectrum for data system communications, spectrum in the 1-3 GHz range is becoming widely used for a range of wireless communications. This results in both the spectrum being expensive as well as potentially having a high level of noise energy, caused by multiple uses of the same channels.

At millimeter wave (mm-wave) frequencies a great deal of spectrum is available. However, such frequencies have disadvantages associated with their use. For example, mm-wave propagation is typically limited to line-of-sight between a BS and a RS. Additionally, mm-wave radio propagation is severely limited by rain and terrain, requiring complex control systems to deal with temporary rain fades or increased transmit power to allow for a worst case scenario. Such increase power, in addition to the obvious expense in such a brute force

solution, can limit reuse of frequencies because of the overlapping radiation patterns experienced when the conditions requiring the increased power are not present or are not fully present in a particular antenna beam. Nevertheless, multibeam antennas can provide benefit to this frequency band.

There are some lower frequencies where spectrum is still available. For example, there is unused personal communications services (PCS) spectrum and under utilized ultra-high frequency (UHF) television channel spectrum available in many geographic regions of the United States. Additionally spectrum associated with multichannel multipoint distribution service (MMDS), 200 MHZ bandwidth at 2.5 GHz, remains available in many areas. These portions of the spectrum often remain under/un-utilized because of the inability of service providers to efficiently and economically allocate the spectrum for use to multiple users.

The problem is further compounded because each RS user may pick up radiated energy interference, or any number of other signal attenuation problems associated with the air interface between the BS and the RS.

In order to provide the desired data rate (data bandwidth) in the available spectrum to multiple users in an efficient and economical manner, it is advantageous to reuse frequencies. The reuse of frequencies in wireless systems has been done in cellular communication systems, where a plurality of BSs are allocated particular frequencies or ranges of frequencies to provide communications in an associated service area and where adjacent BSs or portions thereof are restricted from use of same frequencies. The use of narrow antenna beams in cellular systems can provide capacity gains of 100% or more, compared to ordinary sectorized cellular systems. However, the spectral reuse efficiency is still less than 25%, i.e., at most 25% of the spectrum is available for use at a single site.

To make the best use of such frequencies, what is needed in the art is a robust, spectrally efficient system and method to provide voice and high rate data on demand to multiple geographically dispersed users.

A further need exists for such a system where the RS antennas are adapted to enhance communication without necessarily increasing power.

A still further need exists for such a system in which the RS antenna can assist in the elimination of BS loading or other interference problems.

SUMMARY OF THE INVENTION

These and other objects, features and technical advantages are achieved by a system and method which establishes a wireless system capable of providing high bandwidth data channels, i.e., several megabit data channels, at every BS in a network while using only a small amount of spectrum, i.e., a relative few radio frequency (RF) channels. The antennas at one or more RSs can be adapted to selectively focus on one or more cell sites and can selectively change their reception/transmission beam width or direction (or both), thereby reducing interference problems. It shall be appreciated that as used herein, channels may be comprised of frequency divisions, time divisions, and/or code divisions.

The preferred embodiment of the present invention utilizes a network of BSs deployed in a configuration to provide coverage to the RSs for which it is desired to provide wireless data communication services. For example, the network of BSs could include a deployment of BSs dense enough to assure coverage to a plurality of RSs throughout a particular geographic area, such as a metropolitan area. The RS antennas could use either adaptive phase arrays or beam switched arrays to change (add or subtract) their beam width/direction or to point at different BSs, as the need arises. Thus, if a base site is experiencing excessive loading, it can direct either existing RS (users), or new users, or both to a more lightly loaded (or interference free) site. Also, the beam can be split to avoid an area of concern.

The deployment of BSs to provide wireless data communication services in a defined geographic service area associated with each particular BS shall be referred to herein as having "cells" associated with each BS, wherein RSs disposed within the geographic boundaries of a cell communicate principally with the BS thereof. However, it should be appreciated that deployment of BSs of the present invention is not limited to the regular spacing intervals generally thought of when considering a typical cellular or PCS mobile wireless communication system. For example, it is anticipated that data communication will be provided to fixed point RSs in a preferred embodiment of the present invention. Accordingly, BSs may be deployed such that service areas sufficient to encompass a

predetermined number of fixed point RSs without providing fully blanketed coverage throughout an area.

The BS's of the present invention preferably utilize multiple narrow beam antennas, multiple beam antennas (MBA), capable of directing energy into and out of any antenna beam on command. A preferred embodiment of the BS's of the present invention utilize multiple beam antennas providing 12 substantially non-overlapping antenna beams to provide directional wireless signal coverage in an area 360° around an associated BS. Additionally or alternatively, the multiple beam antennas of the BSs of the present invention may provide antenna beams which substantially overlap, such as to allow redundancy and/or to provide the ability for RSs to change to different channels, such as based on interference conditions.

The RS's of the present invention also preferably utilize multiple narrow beam antennas which could, for example, be a window box with a 150° viewing angle, having 15°steerable beams. Specifically, a most preferred embodiment of the RSs of the present invention utilize multiple beam antennas providing 12 substantially non-overlapping antenna beams to provide directional wireless signal coverage in an area 360° around an associated RS. The use of such directive antennas at the RSs of the preferred embodiment provides for a reduction in signal scattering and, thus, a reduction of unwanted energy in various antenna beams. However, the systems and methods of the present invention will work with some or all of the RSs having omnidirectional antennas. It should be appreciated that the result will be higher system capacity if directive antennas, whether multibeam or not, are used at the RS's. One aspect of a directive antenna is that it can be a smart antenna. In this context, a smart antenna is an antenna that has a relatively narrow horizontal beamwidth, usually under 60 degrees, that can be pointed in a specified direction. The direction that the antenna is pointed can be changed based on different factors such as interference or loading.

Capacity is lowered in the network as radiation from a network BS reaches RSs outside the BSs service area and/or radiation from an RS reaches BSs outside the BS service area in which the RS is operating. This limitation is partially due to the limits on signal isolation of the BS and RS antenna patterns and partially due to signal scattering and propagation conditions. Accordingly, BSs of a preferred embodiment of the present

invention include resources, such as interference cancellers in the receive links, to mitigate outside interference. Where BSs are provided such resources and the RSs are not, capacity is generally a downlink limitation.

Accordingly, a preferred embodiment of the present invention includes resources, such as interference cancellers, at the RSs. However, it should be appreciated that most data applications tend to be non-symmetric, with most of the traffic flowing from the BSs to the RSs, thus diminishing the effect of such downlink capacity limitations. Accordingly, a most preferred embodiment of the present invention forgoes the expense of inclusion of interference cancellers at the network RSs.

The preferred embodiment of the present invention employs systems and methods for determining which beams of a BS may be utilized with a particular channel simultaneously to provide increased data communication without intolerable co-channel interference. Additionally or alternatively, the systems and methods so employed provide determination of which network RSs within a particular cell may be operated simultaneously with tolerable co-channel interference. Accordingly, the present invention operates to determine resource (antenna beam, RS, communication channel, and the like) utilization sequences and combinations (resource utilization solutions) adapted to provide optimal capacity, desired quality/priority of service, and/or like considerations.

In a preferred embodiment, determination of resource utilization solutions in which particular resources may be utilized includes the provision of a database or matrix of a particular cell's resources for which simultaneous use is prohibited. In an alternative embodiment, this database includes additional information such as resource utilization solutions in which particular resources which, although causing undesired results such as co-channel interference, may be utilized at a diminished or reduced capacity. The capacity of a particular cell is optimized according to a preferred embodiment of the present invention by considering signal quality measurements, such as signal to noise ratio (SNR) and/or signal to interference ratio (SIR), as well a capacity needs for each RS in the cell. Accordingly, various resource utilization solutions may be analyzed with reference to the preferred embodiment database in order to determine a resource utilization solution which provides a

desired level of service, whether based on capacity (in either or both the forward and reverse links), quality of service, and/or the like.

A primary reason for using smart antennas at the customer site is to avoid having to manually redirect the antenna when new sites, either BS's or RS's, are added to the network or upon initialization of service the customer can install his own antenna and it will auto find the BS. When a new site is added to the network, the system can request quality measurements from the customer locations and through a combination of quality and loading with respect to different base sites determine which base site would serve the customer best. The smart antenna would then be redirected, either on a per call, per channel, per time, or other basis.

The primary benefits of having a smart antenna at the customer site are:

- Automatic orientation of CPE equipment during installation;
- Automatic reorientation of existing CPE equipment upon installation of a new base site;
- Interference reduction through the use of narrow antenna beams, this includes reduction of self interference due to multipath between BS and RS;
- Automatic selection of the serving base site due to loading; and
- Automatic selection of the serving base site due to interference.

The smart antenna at the customer site has the following features:

- Narrow beamwidth, ideally between 10 and 30 degrees;
- Multiple fixed beams or the ability to scan a single beam. The beam scanning can be accomplished either by physically changing the pointing direction of the antenna, or by changing the phase of the antenna elements, thereby altering the beam pattern, or any combination of the above;
- The ability to scan a beam over a wide range of angles, more than 120 degrees; and

- The ability to select a new serving cell based on instructions from the existing base site or through autonomous measurements.

Accordingly, the preferred embodiment of the present invention examines various combinations of the cell and inter-cell databases, and/or other available BS/RS/beam/channel information, to determine a resource utilization solution which provides a desired level of service, whether based on capacity (in either or both the forward and reverse links), quality of service, and/or the like. Preferably, all BS, beam, channel pairings are examined and assignments with respect to simultaneous usage are made to those pairs that provide a signal quality measurement, such as SIR, that just exceeds a threshold determined to provide a desired quality of service. Accordingly, the greatest number of uses/reuses of the spectrum may be used to provide optimization.

Preferred embodiments of the present invention utilize time division multiple access (TDMA) communication channels to allow time sharing of RF channels among multiple users. Accordingly, the present invention may use the preferred embodiment multi-beam architecture (MBA) to switch or direct energy to the proper antenna during the proper time slot to achieve system optimization as discussed above. Moreover, where bandwidth is available, multiple carriers may be simultaneously utilized in the multiple antenna beams to provide additional capacity.

Additionally, or alternatively, embodiments of the present invention utilize CDMA communication channels to allow code sharing of RF channels among multiple users. For CDMA systems, the greatest efficiency occurs when transmission and reception between a BS and RS occur only on a single beam. Accordingly, embodiments of the present invention using CDMA, or other interference limited channels, acquire and identify the strongest received signal beam from an individual BS, such as by performing a correlation of the target RS on all BS antenna beams. Thereafter, the present invention may use the MBA to switch or direct energy to particular antenna beams to achieve system optimization as discussed above.

Variable data rates are used in a preferred embodiment of the present invention. Accordingly, higher data rates may be provided between a BS and particular RSs, where

conditions allow. For example, in the above described CDMA embodiment higher capacities may be achieved through increased reuse and/or coding gain decrease. RSs disposed relatively close to a BS (RSs experiencing low path loss between the BS and RS) do not require highly spread codes to achieve low error rate data. Accordingly, allowing higher bit energy to noise density (E_b/N_0) for RSs which require little power can be traded for a slight rise in E_b/N_0 for other RSs. Having a higher E_b/N_0 allows changing spreading codes to get higher throughput according to one embodiment of the present invention.

Similar concepts are applied in TDMA system of the present invention. Specifically RSs which are disposed relatively close to a BS, or otherwise receive a strong signal, can operate at a reduced power level and/or establish a link with a higher data rate. For example, quadrature amplitude modulation (QAM) is an example of modulation where the same bandwidth, i.e., the same baud rate, provides multiple levels of modulation. Various orders of QAM are utilized according to one embodiment of the present invention to obtain higher throughput.

As described above, in a preferred embodiment of the present invention, restrictions exist on the simultaneous use of two or more antenna beams in a cell using a same channel. Accordingly, sectors may be established which define channel sets and/or antenna beams which may be used simultaneously. The highest capacity is likely to be achieved when each sector carries an equal share of the data traffic. Accordingly, a preferred embodiment of the present invention provides for variable sector boundaries to allow dynamic adjustment of sectors depending on traffic conditions on an entire cell.

As described above, the present invention provides a robust, spectrally efficient system and method to provide voice and high rate data on demand to multiple geographically dispersed users. A technical advantage of the present invention is that efficient use of available frequencies may be made in providing high data rate communications. A further technical advantage is provided in determining which antenna beams and which RSs can operate simultaneously with tolerable co-channel interference in order that optimal capacity may be achieved.

The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWING

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawing, in which:

FIGURE 1 shows a preferred embodiment multiple beam cell utilized according the present invention;

FIGURE 2 shows alternative embodiments of base station circuitry of the present invention;

FIGURE 3 shows reuse of channels by the circuitry of FIGURE 2;

FIGURE 4 shows a network of cells according to the present invention;

FIGURE 5 shows flow diagrams of the identification of antenna beams for communication at remote stations and at base stations;

FIGURE 6 shows the degradation of a signal with varying amounts of interference;

FIGURE 7A shows a cell adapted to provide reuse of channels according to the present invention;

FIGURE 7B shows preferred embodiment optimization circuitry for the optimization of data packets for the channel reuse of FIGURE 7A;

FIGURE 8 shows a network of cells according to the present invention;

FIGURES 9 and 10 show preferred embodiment circuitry for the acquisition of most preferred antenna beams;

FIGURE 11 shows a preferred embodiment data container for a forward link access channel;

FIGURE 12 shows progression of the forward link access channel through a preferred embodiment multiple beam antenna;

FIGURE 13 shows a preferred embodiment data container for a reverse link access channel;

FIGURE 14 shows a preferred embodiment data container for a direction message;

FIGURE 15 shows preferred embodiment TDD circuitry of the present invention;

FIGURE 16 shows overlap experienced in reuse of TDD channels;

FIGURE 17 shows two base sites available to service a particular customer;

FIGURE 18 shows a third base site available to service the particular customer;

FIGURE 19 shows one possible configuration for a customer's site;

FIGURE 20 is a flow chart showing implementation of one possible system;

FIGURE 21 shows a possible base site system; and

FIGURE 22 shows a possible remote site system.

DETAILED DESCRIPTION

The present invention is directed to a wireless system capable of providing several megabit channels at a plurality of base stations (BSs) in a communication network while using only a few RF channels. According to the preferred embodiment of the present invention, a relatively small amount of spectrum is utilized by the present invention in providing high data rate communications to a number of geographically dispersed remote stations (RSs). In order to provide a desired high data rate (high data bandwidth) in the available spectrum to multiple users in an efficient and economical manner, reuse of frequencies and/or other communication channels is preferably utilized. In the preferred embodiment, multiple antenna beams are provided in order to facilitate the reuse of communication channels at a cell and/or within the communication network.

A preferred embodiment of the present invention uses TDMA to time share a single resource (frequency, channel, etcetera) among multiple users. The best mode would seem to be a fixed remote or a slowly moving remote. However, the invention is not limited to such systems. In utilizing TDMA techniques with the MBA of the preferred embodiment, a switch or other controllable circuitry is used to direct energy to the proper antenna beam during the proper time slot. Alternatively, an adaptive antenna may "point" an antenna beam directly at each user and quickly re-point to another user. This has more complex circuitry, but works the same for systems where any one antenna beam needs only a fraction of the system capacity, such solutions are very efficient. It should be appreciated that in an adaptive array one such adaptive antenna beam may be utilized to provide signals in various azimuthal angles as well as a variety of radiation pattern shapes. Accordingly, multiple beams and multiple beam antennas as used herein includes an adaptive array providing a single antenna radiation pattern at any one instant, as well as those providing multiple simultaneous antenna beams. Adapter arrays can also direct nulls toward interfering sources.

Hybrid systems, wherein both adaptive arrays and fixed beam arrays are used, may be utilized according to the present invention. For example, a preferred embodiment of the present invention utilizes an adaptive array (or feed network coupled to a common antenna array) on the uplink and a fixed beam array (or feed network coupled to the common antenna

array) on the downlink. Accordingly, selection of a downlink antenna beam to use may be made from the uplink signals to provide a system which adapts on a per user basis for the uplink and selects one of N fixed beams for downlink transmission.

Growth scenarios with multibeam TDMA are simple. For example, initial deployment may begin with one RF carrier per BS. Thereafter as demand dictates, and where bandwidth is available, another carrier may be delegated to the BS. Using linear power amplifiers (LPAs), multiple carriers may be communicated through the same antenna beam simultaneously. Alternatively, restricting usage to different antenna beams for different carriers may avoid the use of LPAs, although such a configuration reduces flexibility and throughput. If neighboring BSs in a communication network have different RF channels, then growth at each BS, as well as the utilization of the RF channels, proceeds independently. However, according to a preferred embodiment of the present invention, reuse of channels, both within a cell and throughout neighboring cells, is utilized according to resource utilization solutions which may be optimized to achieve increased capacity and/or desired levels of throughput, quality of service, etcetera.

A preferred embodiment of the present invention uses CDMA to code share a single resource (frequency, channel, etcetera) among multiple users. In utilizing CDMA techniques with the MBA of the preferred embodiment, the greatest efficiency occurs when transmission and reception between a BS and RS occur only on a single beam of the BS. This is because CDMA techniques are interference limited. Therefore, limiting the area in which a particular code signal is radiated will reduce the energy level experienced outside this area and, thus, allow additional capacity in these areas. Accordingly, a preferred embodiment of the present invention provides selective coupling of signals to particular antenna beams of the MBA, such as through a switch matrix or other controllable circuitry, or form multiple beams aimed at individual RSs.

BS 101 adapted according to the present invention is shown in FIGURE 1 as having a set of, preferably 12, narrow antenna beams (beams 111-122) providing wireless communication within cell 102. BS 101 is preferably adapted to direct energy into and out of

any antenna beam on command. A preferred embodiment of circuitry of BS 101 adapted as described above is shown in FIGURE 2.

It should be appreciated that the multiple narrow antenna beams utilized according to the present invention may be provided by a multiple beam antenna array, by individual antennas adapted to provide narrow beams, or by any other means deemed desirable. Additionally, it should be appreciated that the number of antenna beams utilized according to the present invention is not limited to the 12 antenna beams illustrated. The antenna beams utilized according to the present invention may be formed from a fixed beam array (such as a Butler matrix switched beam array) or from adaptive array (such as an adaptive beam forming array using adjustable phase progressions and weighting to form antenna beams and nulls).

Moreover, embodiments of the present invention may include multiple elevation angles per antenna beam or per antenna beam azimuthal position. Accordingly, increased capacity may be achieved by further isolating the communication of signals, such as by dedicating more unique pointing slots in a signal. Communication timing may cycle through X azimuth angles at 0° and then Y azimuth angles for a next elevation angle, and so on.

As shown in FIGURE 2A, BS 101 includes BS radio 201 coupled to antennas 211-222 through switch matrix 202 to direct energy between any of antennas 211-222 and BS radio 201 (into and out of beams 1-N) on command. Control of switch matrix 202 and/or radio 201 is preferably provided by a processor based control system (BS controller 203), preferably having a central processing unit, memory, and a control algorithm operable therewith. It should be appreciated that BS controller 203 may be adapted to provide additional functionality such as digital signal processing (DSP), interference canceling, signal quality analysis, and the like.

According to the preferred embodiment of the present invention, simultaneous use of the same RF channel on 2 or more antenna beams in a single cell, such as cell 102, is possible. One overriding determinant of such reuse is antenna beam isolation. Some antennas are better than others at providing isolation, but cost and size is an issue. Additional beam isolation can be obtained by using cross polarization transmission at adjacent beams. Cross polarization in a same beam is technically possible, but such an embodiment tends to

cause the BS to be very expensive. Regardless of how isolation is provided, an RF carrier is preferably dedicated to a particular sector of the cell, defined as using K beams where K may be as narrow as one antenna beam or may encompass a full 360°.

Accordingly, alternative embodiments of the circuitry of BS 101 are shown in FIGURES 2B through 2D. For example, FIGURE 2B shows 2 BS radio units, BS radio 201b and BS radio 204b, coupled to antennas 211-222. However in this embodiment BS radio 201b is coupled to antennas 1 through k (here antennas 211-215 preferably defining a first sector) through switch matrix 202b, while BS radio 204b is coupled to antennas k+1 through n (here antennas 216-222 preferably defining a second sector) through switch matrix 205b. Control of switch matrixes 202b and 205b and/or radios 201b and 204b is preferably provided by BS controller 203b, preferably configured substantially as BS controller 203 described above.

Each of BS radios 201b and 204b are preferably adapted to provide communications on a same channel or channels as the other one of BS radios 201b and 204b. Accordingly, as shown in FIGURE 3A, a same channel may be utilized within cell 102, such as at both beam 113 associated with BS radio 201b and beam 118 associated with BS radio 204b, to provide increased communication capacity within the cell as compared with the exclusive use of available channels within that cell.

FIGURE 2C shows 3 BS radio units, BS radio units 201c, BS radio 204c, and BS radio 206c, coupled to antennas 211-222. However in this embodiment BS radio 201c is coupled to antennas 1 through k (here antennas 211-214 preferably defining a first sector) through switch matrix 202c, while BS radio 204c is coupled to antennas k+1 through l (here antennas 215-218 preferably defining a second sector) through switch matrix 205c, and while BS radio 206c is coupled to antennas l+1 through n (here antennas 219-222 preferably defining a third sector) through switch matrix 207c. Control of switch matrixes 202c, 205c, and 207c and/or radios 201c, 204c, and 206c is preferably provided by BS controller 203c, preferably configured substantially as BS controller 203 described above.

Each of BS radios 201c, 204c, and 206c are preferably adapted to provide communications on a same channel or channels as the other one of BS radios 201c, 204c, and

206c. Accordingly, as shown in FIGURE 3B, a same channel may be utilized within cell 102, such as at each of beams 111 associated with BS radio 201c, 115 associated with BS radio 204c, and 119 associated with BS radio 206c to provide increased communication capacity within the cell as compared with the exclusive use of available channels within that cell.

FIGURE 2D shows 4 BS radio units, BS radio units 201d, BS radio 204d, BS radio 206d, and BS radio 208d coupled to antennas 211-222. However in this embodiment BS radio 201d is coupled to antennas 1 through k (here antennas 211-213 preferably defining a first sector) through switch matrix 202d, while BS radio 204d is coupled to antennas k+1 through *l* (here antennas 214-216 preferably defining a second sector) through switch matrix 205d, while BS radio 206d is coupled to antennas *l*+1 through m (here antennas 217-219 preferably defining a third sector) through switch matrix 207d, and while BS radio 208d is coupled to antennas m+1 through n (here antennas 220-222 preferably defining a fourth sector) through switch matrix 209d. Control of switch matrixes 202d, 205d, 207d, and 209d and/or radios 201d, 204d, 206d, and 208d is preferably provided by BS controller 203d, preferably configured substantially as BS controller 203 described above.

Each of BS radios 201d, 204d, 206d, and 208d are preferably adapted to provide communications on a same channel or channels as the other one of BS radios 201d, 204d, 206d, and 208d. Accordingly, as shown in FIGURE 3C, a same channel may be utilized within cell 102, such as at each of beams 113 associated with BS radio 201d, 116 associated with BS radio 204d, 119 associated with BS radio 206d, and 122 associated with BS radio 208d to provide increased communication capacity within the cell as compared with the exclusive use of available channels within that cell.

It should be appreciated that the use of separate radios and/or separate switching circuits is not required according to the present invention. For example, radio circuitry capable of providing separate communications on a same channel to multiple RSs may be utilized according to the present invention. In addition to there being no limitation that separate switching circuitry or radios be used, there is no limitation to the use of particular antenna beams with particular radios and/or channels according to the present invention. For

example, multiple radios may be coupled to a switching array allowing connection of any radio to any antenna beam, alone or in combination, if desired. Additionally, it should be appreciated that, as shown in the embodiment of FIGURES 2B and 3A, there is no limitation to there being an equal number of antenna beams associated with radios, channels, or other resources, according to the present invention. Likewise, there is no limitation to the antenna beams being the same size, or even of a fixed size, according to the present invention.

The highest capacity will generally be achieved when each sector of a BS carries a substantially same traffic load and/or cells of the network carry a substantially same traffic load. Accordingly, a preferred embodiment of the present invention utilizes variable sector boundaries to allow loading to be balanced between the sectors. For example, during particular parts of a day or week particular RSs may require more data capacity than other times of the day or week. If changes in required data capacity are not substantially uniformly distributed amongst the sectors, a switching matrix or other controlled coupling circuitry may be utilized to adjust the coupling of antenna beams to communication equipment, such as traffic channel radios, pilot radios, and the like, to redefine sector boundaries, such as those described above with respect to FIGURES 2B-2D. Systems and methods for providing dynamic adjusting of sector sizes utilizing multiple antenna beams are shown and described in United States patent number 5,889,494, the disclosure of which is incorporated herein by reference.

In addition to operational determinations made with respect to traffic in various sectors of a BS as described herein, a preferred embodiment of the present invention utilizes inner cell communication/control to optimize operations. For example, the above described load balancing may be accomplished at least in part through handing communications off to an adjacent cell. Additionally or alternatively, such inter-cell communication/control may be utilized to provide network load balancing. Systems and methods for providing such inter-cell communication/control are shown in United States patent number 5,884,147, entitled "Method and Apparatus for Improved Control over Cellular Systems," the disclosure of which is incorporated herein by reference.

Experimentation has revealed that a BS which can select the most preferred one of 12 narrow antenna beams which cover a service area, as compared to an omnidirectional antenna covering the same service area, has an 11 dB advantage in terms of interference rejection and power transmitted. Even more benefits in terms of reduced interference and radiated power occur when the RS is capable of directing a narrow beam antenna toward the best servicing BS. Accordingly, the greatest efficiency in the use of available resources according to a preferred embodiment of the present invention occurs when transmission and reception between a BS and RS occur only on a single antenna beam of the BS. According to a preferred embodiment, a most preferred antenna beam for communications with each active RS is identified and subsequent communication occurs using this most preferred antenna beam. Preferably, the most preferred antenna beam for each RS is an antenna beam having a "strongest" signal associated with that RS. It should be appreciated that the antenna beam determined according to the present invention to be the "strongest" may meet criteria other than or in addition to the received signal strength of greatest magnitude. For example, the determination of "strongest" may be made for an antenna beam having the best signal quality, i.e., highest SIR or SNR, the most direct path or shortest path, or the like. Likewise, an adaptive beam former can create a "strongest" beam to the RS using similar criteria.

A difficulty in using multiple beam antennas is in the initial assignment and subsequent tracking of the best serving base station and the most preferred antenna beam associated therewith. The difficulty is exacerbated in TDMA system, where it becomes important to know both when and where antenna beams are pointing and the distance between the BS and RS. To some extent utilizing an omnidirectional antenna beam can aid in acquisition, but the use of an omnidirectional antenna beam in combination with the multiple antenna beams adds to the complexity of both the BS and the RS and typically would not provide information with regard to selection of a most preferred antenna beam. Therefore, the preferred embodiment of the present invention provides a technique to initialize and track multibeam antennas at both a BS and RS without using omnidirectional antennas.

Acquiring and identifying the most preferred antenna beam at the BS is preferably performed by the BS correlating the target RS on all antenna beams, or some subset thereof

determined to be candidates for establishing communications with the target RS. Since "strongest" antenna beams rarely change in a fixed point communication system, as opposed to mobile cellular systems where the strongest antenna beam can potentially change several times per second, determining the correct antenna beam for a fixed RS is not generally a time critical issue. Shown in FIGURE 9 is preferred embodiment circuitry adapted to provide time shared acquisition of most preferred antenna beams. Accordingly, correlation circuitry is provided which is coupled to the multiple antenna beams through a switch matrix, allowing antenna beams to be selectively provided to the correlator for determination of a most preferred antenna beam.

Where determination of a most preferred antenna beam is more time critical, such as where ones of the RSs are likely to change position and/or where propagation conditions are subject to material change, the simultaneous acquisition circuitry of FIGURE 10 may be more desired. In the embodiment of FIGURE 10, each antenna beam is provided with associated correlation circuitry in order to allow simultaneous acquisition of a signal on all antenna beams.

According to a preferred embodiment, where timing is divided into bits, slots, frames, superframes, etcetera, with N_1 bits/slot, N_2 slots/frame, N_3 frames/superframe, etcetera, initialization occurs using a dedicated multiple beam antenna access channel (MBAACH). A preferred embodiment MBAACH data container is shown in FIGURE 11 as packet 1100.

The preferred embodiment MBAACH data container of FIGURE 11 includes synch bits, overhead information, RSSI information, number of antenna beams, current antenna beam, and directed message. The synch bits of the preferred embodiment set the beginning of the MBAACH message. The overhead information includes information such as system identification, number of carriers, BS identity, timing information, etcetera. The RSSI information is information designed to allow the quick determination of received signal strength. The number of antenna beams information provides information regarding the number of antenna beams associated with this carrier and, preferably, the pointing angles of these antenna beams. The current antenna beam information provides the current antenna

beam number and pointing angle. The directed message provides instructions to individual RSs.

Preferably, the MBAACH is provided in a slot of a traffic channel. Accordingly, one slot of the traffic channel is dedicated to beam acquisition, paging, and slot assignment. The frequency of occurrence of a MBAACH slot depends on the number of users and the desired set-up time.

In operation according to a preferred embodiment, a BS is aligned with antenna beam 1 facing north, antenna beam 2 facing north easterly, etcetera as illustrated in FIGURE 1. Preferably, for the MBAACH, slot 1 corresponds to the MBA pointed in direction 1, in the next repetition of the MBAACH slot, the MBA would point in direction 2, etcetera. The progression of the MBAACH slots according to this embodiment of the present invention is shown in FIGURE 12.

According to the preferred embodiment, the RS listens for the synch burst and attempts to measure the signal strength. Most of the time the RS will measure low values for the signal strength. As the MBA points toward the RS, the signal strength will increase. If the RS also has a MBA, then after every K frames, corresponding to the BS having stepped through every pointing angle or every pointing angle associated with a particular carrier, the RS will preferably increment its MBA by one antenna beam and repeat the search. Preferably, after exhausting all angels, the RS increments to the next RF carrier. The RS preferably logs the carrier numbers and the beam numbers that produce a strongest receive signal strength, for example a first and second most preferred carrier and beam combination may be determined. Thereafter the RS preferably adjusts its antenna beam angle to the strongest BS and transmits in the time slot reverse link dedicated to MBA access channel (reverse MBAACH) information regarding the most preferred carrier and beam combination. For example, the RS locks onto the best carrier, antenna beam, receive signal strength combination and transmits the reverse MBAACH to the appropriate BS.

A preferred embodiment reverse MBAACH data container is shown in FIGURE 13. The preferred embodiment reverse MBAACH data container of FIGURE 13 includes a leading and trailing guard time, synch bits, RS identification information, and report message.

The guard times are adapted to prevent the RS from accidentally transmitting and overlapping its transmission with other RSs, i.e., the guard band insures that messages from distant RSs arrive within the time window of a time slot and do not overlap with other RSs on adjacent slots. The synch bits of the preferred embodiment set the beginning of the reverse MBAACH message. The RS identification information identifies the RS sending the reverse MBAACH message. The report message provides information such as carriers detected, angles and beam numbers above threshold, etcetera.

After having provided the appropriate information in the reverse MBAACH, the RS listens on a direction MBAACH portion of the channel, corresponding to the beam number used, for a unique message. The received direction message of a preferred embodiment may instruct the RS that the identified best carrier, angle and beam is acceptable for communication or, if unavailable, perhaps to look for another BS or RF carrier.

A preferred embodiment of the direction message from the BS is shown in FIGURE 14. The preferred embodiment direction message includes synch bits, RS identification information, BS identification information, carrier number, antenna beam number, timing advance information, and end bits. The synch bits of the preferred embodiment set the beginning of the direction message. The RS identification information identifies the RS to which the direction message is directed. The BS identification information identifies the BS from which the direction message was sent. The carrier number identifies the carrier to which the direction message relates. The beam number identifies the beam to which the direction message relates. The timing advance information provides timing information related to the RSs relative position to the BS in order to allow reduced reliance on guard times in communication of data packets. The end bits set the end of the direction message.

In the preferred embodiment, operation of the present invention in initializing antenna beams, carriers, and the like as described above, includes protocols for handling messages which are corrupted or collide. For example, each RS may be assigned a particular reverse MBAACH time slot in order to avoid collisions in providing the reverse MBAACH message. Additionally or alternatively, the RS may wait for a particular predetermined time for a direction message from the BS and if not received therein, retransmit the reverse MBAACH

message due to its having collided with another message or otherwise having been corrupted as received at the BS.

It should be appreciated that the above described initialization technique allows MBA antennas at both the BS and the RS to align themselves. Moreover, such alignment may be accomplished prior to, and independent of, any other application.

For forward links it is often customary to use a pilot signal, different at each BS, so that a RS can identify the BS with the best or most preferred signal path. In a preferred embodiment, the forward and reverse path antenna beams are selected to be the same, since it is likely the forward and reverse links will experience the same or similar propagation conditions. Accordingly, in the preferred embodiment either the BS or RS may be equipped to determine the most preferred antenna beam for each.

For a single cell, such as that shown in FIGURE 1, beam-to-beam isolation is an important factor in determining the cell capacity, as the ability to reuse a communication channel of BS radio 201 simultaneously in any of beams 1-N depends on the ability of the antenna beams to isolate the signal from other ones of beams 1-N. Isolation in free space can be increased through the use of improved antenna designs, such as designs which provide lower sidelobes, reduced back scatter, and the like. However, in practice scattering around the BS and RSs causes unwanted energy to appear in beams other than that intended. Scattering near the BS can be reduced by raising the BS above local obstacles, however this is not always practical due to zoning and other restrictions. Scattering around the RS can be reduced by using directive antennas pointing toward the BS. The present invention will operate with some or all of the RSs having omnidirectional or broad beam antennas. However, in order to provide higher system capacity, the preferred embodiment of the present invention uses directive antennas at some or all RSs. Accordingly, a preferred embodiment RS according to the present invention utilizes a multibeam antenna substantially as shown in FIGURE 1.

In order to provide communication services to a number of RSs disposed throughout a geographic area, the preferred embodiment of the present invention utilizes a plurality of BSs such as BS 101 of FIGURE 1 to establish a cellular communication network. The system

preferably determines a BS which a RS should be served by through reference to existing and learned network conditions. For example, reference may be made to traffic patterns, interference conditions, loading, and the like. Additionally or alternatively, signal strength maybe utilized in determining a BS to serve a particular RS.

A simple multibeam BS network is illustrated in FIGURE 4. It should be appreciated from the network of FIGURE 4 that the antenna beams utilized according to the present invention are not limited to a particular number or even a particular size. As shown in FIGURE 4, various size antenna beams may be utilized, such as where RSs within a cell are not evenly distributed and thus loading on the various antenna beams may be balanced.

BSs 401 and 403 of FIGURE 4, preferably each configured substantially as illustrated in FIGURE 2, are deployed to provide communication services within cells 402 and 404 respectively. Disposed at various positions throughout cells 402 and 404 are RSs 451-455 (cell 402) and 461-464 (cell 404) being provided communication services by BSs 401 and 403. The communication services provided to these RSs include high rate data services, such as 1 MB/s data communications. However, as the RF spectrum is limited and expensive, operation of the present invention efficiently utilizes the available spectrum to provide each of the RSs the desired communication services.

As the designs of most practical antennas trade physical size and other practical considerations against beam-to-beam isolation, it is assumed that adjacent antenna beams of an antenna system utilized according to the present invention will couple too much energy to carry separate independent signals of a same communication channel. Therefore, according to a preferred embodiment of the present invention, adjacent beams are not allowed to transmit a same communication channel simultaneously. Although this restriction may be avoided by cross-polarization or other isolation techniques, but such an embodiment may require RSs to have dual polarity antennas which would tend to increase their cost. For example, referring to FIGURE 4, at BS 401 RSs 451, 453, and 455 or 452, 454, and 455 may be served with the same channel simultaneously. However, RSs 452 and 453 would not be served with the same channel simultaneously because it is expected that the antennas utilized at BS 401 cannot provide sufficient signal isolation.

It should be readily appreciated from the illustration in FIGURE 4, that the problems of co-channel interference are not limited to communications associated with BS 401. For example, RS 453 of BS 401 and RS 462 of BS 403, if simultaneously operating on a same communication channel may experience co-channel interference. However, depending on the relative power levels at RSs 453 and 462, and the discrimination of the RS antennas, co-channel interference at RSs 453 and 462 may be limited or avoided. Accordingly, a preferred embodiment of the present invention utilizes directional antennas at some or all of the RSs. Such directional antennas may, for example, be a single narrow beam focused on a particular BS or may be a multiple beam array such as illustrated in FIGURE 1 suitable for establishing communication with multiple network BSs.

In addition to the above described co-channel interference associated with RSs which, although being disposed in different cells, are located in relative close proximity, more distant RSs may too experience co-channel interference. For example, RS 461 may "see" BS 401, i.e., receive a signal from BS 401 with sufficient amplitude to cause undesired results at RS 461, when BS 401 transmits to RS 453. However, if the signal from BS 403 to RS 461 is sufficiently strong, then both RS 453 and RS 461 can operate simultaneously on a same communication channel according to the present invention. It should be appreciated that various network parameters may be adjusted to allow the signal between BS 403 and RS 461 to be sufficiently strong to allow the simultaneous operation of RSs 453 and 461. For example, the power level of a signal transmitted from BS 401 to RS 453 may be reduced to a level sufficiently low for simultaneous operation of RS 461, while sufficiently high to provide a desired quality of service at RS 453. Additionally or alternatively, the power level of a signal transmitted from BS 402 to RS 461 may be increased to a level sufficiently high for simultaneous operation of RSs 461 and 453, while sufficiently low to avoid causing undesired results in other communication links of the network.

A preferred embodiment of the present invention operates to determine which network resources, i.e., which antenna beams and RSs, may be operated on a same channel simultaneously with tolerable co-channel interference so that optimal capacity can be achieved in the network. Preferably, such determinations are made on various system levels,

such as determinations with respect to each BS considered alone (intra-cell interference) and determinations with respect to RSs outside the coverage area of each BS (inter-cell interference).

The discussion below with respect to the determining of acceptable simultaneous use of network resources assumes previously measured and/or well modeled radiation paths, e.g., empirically measured communication attributes (whether during live communications or during a test period) and/or computer modeling of interference conditions based upon know propagation characteristics. It should be appreciated that such measurements may be incorporated as an integral part of the communication network and would require only a small fraction of the network capacity to keep current. For example, BS 101 as illustrated in FIGURE 2 may include a signal quality, or other attribute, measurement apparatus, such as a receive signal strength indicator (RSSI), SNR, and/or SIR measurement device, disposed in the signal path between BS radio 201 and switch matrix 202 to measure the signals coupled thereto. Additionally or alternatively, each of the antenna beams 1-N may be switchably coupled to such a measurement apparatus, such as through a port on switch matrix 202 or through inclusion of a second switch matrix, to allow selection of antenna beams for signal quality measurement independent of the operation of radio 201. Similarly, each or ones of the RSs may include signal quality measurement apparatus. Several techniques allow individual RSs a way to report their measurements. For example, in TDMA systems polling, slotting, time assigned and/or random reporting, with repeats if collisions occur, are all techniques which may allow an RS a clear time slot to report.

The signal attribute information may be communicated to a centralized processor operable to control or otherwise process information for all or several of the BSs. Additionally or alternatively, this information may be utilized at each of the BSs, such as by the above described BS controller, to control operation of the BS.

In a preferred embodiment of intra-cell interference determinations it is assumed that each RS is aimed at the BS that provides the greatest strength signal, such as using the steps described above. Accordingly, a communication path may be set up so that from time to time each RS logs onto the network and identifies what BS and what beam provides the strongest

signal thereto. Of course, it should be appreciated that the use of multiple antenna beams at the RSs is within the scope of the present invention and, thus, an antenna beam aimed at the BS may be but one of a plurality of RS antenna beams (others of which may be aimed at other BSs). Similarly, omni directional antenna beams at the RS are within the scope of the present invention and, thus, aiming of such a beam may correspond to deployment such that communications are possible.

Directing attention to FIGURE 5A, an algorithm operable to cause RSs to periodically identify and provide BS antenna beam selection information to the network is shown. This algorithm is preferably operable on a processor based system of the RS and provides control of the RS to identify the desired antenna beam information and provide this information to a corresponding network system, such as the aforementioned BS or network controller. Specifically, at step 501 a determination is made as to whether an antenna beam determination event has occurred. This event may be a predetermined time period, a threshold amount of data communication having been accomplished, a threshold data error rate (such as a bit error rate (BER)), a predetermined signal quality level not having been maintained, or the like. If the triggering event has not transpired, then processing loops back to step 501 to forego further antenna beam determination processing until the event has transpired.

If the triggering event has transpired, processing continues to step 502 where the BS antenna beam providing the a most desired signal attribute, such as a strongest signal, is identified. A preferred embodiment technique providing identification of a BS antenna beam and/or RS antenna beam according to the present invention is described in detail above with respect to the MBAACH.

It should be appreciated that identification of a BS antenna beam at step 502 is not limited to a best or most desired antenna beam. Accordingly, a determination may be made as to whether the RS receives energy above an interference threshold on BS antenna beams other than the strongest BS antenna beam. For example, a first and second best antenna beam may be identified in order to readily identify an alternative communication link in case of communication anomaly or in order to select optimized resource utilization solutions.

Likewise, identification of a BS antenna beam at step 502 may encompass a determination of various ones of multiple RS antenna beams the signal of a particular BS antenna beams is/are best or otherwise desirable.

After a BS antenna beam has been identified at step 502, processing continues to step 503. At step 503 information regarding the BS antenna beam is provided to the network. As discussed above, this information may be provided to the "home" BS for that particular RS, it may be provided to a centralized controller, or the like. Irrespective of the particular network element to which the information is provided, after submitting the information to the proper network element processing loops back to step 501 to await the next occurrence of a determination triggering event.

According to the preferred embodiment, each BS logs the signal strength or other signal attribute from the RSs operable therewith (preferably the RSs located in a cell associated therewith, and alternatively including the RSs disposed in a position suitable for establishing communications of a desired signal quality therewith) on various antenna beams of that BS. Preferably logging of RS signal attributes are for each antenna at the BS so as to determine the interference levels likely to be experienced with simultaneous communication with another RS in any area of the cell.

Directing attention to FIGURE 5B, an algorithm operable to cause BSs to periodically measure signal attributes associated with RSs in communication therewith (or for which communication therewith is possible) is shown. This algorithm is preferably operable on a processor based system of the BS, such as the above described BS controller. The information measured may be retained by the BS and/or provided to other network systems if desired.

At step 510 a determination is made as to whether a triggering event has transpired for the determining of RS beam information. This event may be a predetermined time period, a threshold amount of data communication having been accomplished, a threshold data error rate (such as a BER), a predetermined signal quality level not having been maintained, or the like. If the triggering event has not transpired, then processing loops back to step 510 to forego further antenna beam determination processing until the event has transpired.

If the triggering event has transpired, processing continues to step 511 where an RS is selected for signal measurements. As previously mentioned, the RS may be selected from those RSs disposed within the cell associated with the BS or RSs capable of communications with the BS (i.e., RSs disposed within or relatively near the BS). Additionally or alternatively, RSs may be selected from a subset of those RSs meeting a particular criteria, such as those experiencing a particular error rate, signal quality, data throughput, or the like.

After selection of the RS for measurement a first antenna beam of the multiple BS antenna beams is selected for measurement with respect to the selected RS (step 512). Of course, it should be appreciated that there is no limitation to the particular order of selection of the RS and antenna beams according to the present invention. Accordingly, the present invention is not limited to the order of steps illustrated in the preferred embodiment.

At step 512 the antenna beam is preferably selected from all the BS antenna beams so as to provide for measurement of signal attributes associated with the selected RS on each BS antenna beam. In alternative embodiments selection of the antenna beams may be from a subset of available antenna beams, such as only those likely to receive a signal of consequence from the selected RS based on modeling predictions.

After selection of the BS antenna beam for measurement has been made, processing proceeds to step 513 where desired signal attributes of the selected beam with respect to the selected RS are measured. As discussed above, the measured signal attributes may include RSSI, SNR, SIR, BER, and/or the like.

Thereafter, a determination is made as to whether there are additional BS antenna beams for which measurements with respect to the currently selected RS are desired (step 514). If there are additional BS antenna beams for which measurements are desired, such as if all BS antenna beams or the BS antenna beams of a preselected subset have not been measured for the selected RS, processing proceeds to step 515.

At step 515 a next BS antenna beam of the antenna beams for which measurements are to be made is selected. Thereafter processing proceeds again to step 513 for measurement of the signal attributes.

If at step 514 a determination is made that no additional BS antenna beams are to be measured with respect to the currently selected RS, processing continues to step 516. At step 516 a determination is made as to whether there are additional RSs for which measurements are desired. If there are additional RSs for which measurements are desired, such as if all RSs within the cell or in communication with the BS have not been measured, processing proceeds to step 517.

At step 517 a next RS of the RSs for which measurements are to be made is selected. Thereafter processing proceeds again to step 512 for selection of a first BS antenna beam for measurement.

If at step 516 a determination is made that no additional RSs are to be measured, processing returns again to step 510 to await a measurement triggering event.

After inter-cell interference data is determined, preferably using the algorithms discussed above, the preferred embodiment of the present invention operates to create a forbidden beam matrix. Such a matrix is preferably created for each BS individually, such as one for BS 301 of FIGURE 4 and another for BS 403 of FIGURE 4. An example of a portion of a forbidden beam matrix is illustrated in the table below.

	Beam 1	Beam 2	Beam 3	Beam 4	Beam 5	Beam 6	Beam 7	...
Beam 1	-	X	R					
Beam 2	X	-	X	R				
Beam 3	R	X	-	X	R			
Beam 4		R	X	-	X	X	R	
Beam 5			R	X	-	X		
Beam 6				X	X	-	X	
...								

In operation there may be several RSs per beam. It should be appreciated that not all RSs in a particular beam will cause the same inter-beam interference. Therefore, in the

preferred embodiment forbidden beam matrix is statistically determined based on the probability of interference considering each RS disposed in the particular antenna beams. However, in an alternative embodiment, forbidden beam matrixes may be developed with respect to individual ones of the RSs, if desired.

It should be appreciated that in a preferred embodiment TDMA system, only one RS is served per BS antenna beam channel at any one time slot. Interference may occur on the downlink when a RS disposed relatively far from the BS in the primary beam requires extra power. This extra energy may cause energy to "spill over" into adjacent BS antenna beams. If the energy is simply in the beam side lobes, it can be easily determined mathematically whether simultaneous usage of the same channel a beam or so away from this primary beam is feasible. However, when the energy from the primary beam is scattered to adjacent beams, such as due to terrain conditions, this situation is preferably measured using a reporting system. For example, the measurement algorithms above may make measurements based on various signal transmission levels to emulate or model disposition of RSs far and/or near. Additionally, or alternatively, measurements may be made during actual communication operations to thereby measure actual use conditions, including the power levels at which particular communications links are operated.

It can readily be appreciated from the table above that, with respect to one particular BS of the exemplary communication network, antenna beams 1, 2, and 3 exclude their nearest neighbors while antenna beam 4 excludes simultaneous use of antenna beams 3, 5, and 6. In this example, resources (i.e., channels and/or antenna beams) would preferably be allocated to avoid simultaneous use of the indicated antenna beams with respect to a same channel so that intolerable co-channel interference does not occur.

It should be appreciated that information in addition to the above shown forbidden simultaneous antenna beam information may be utilized according to the present invention. For example, information may be associated with each antenna beam, either within the above shown forbidden antenna beam table or external thereto, which provides network communication information of interest. Specifically, information regarding particular RSs disposed within particular antenna beams, information regarding position and/or distance of

the RSs, information regarding the quality of service and/or capacity needs for the RSs, and the like may be stored and/or utilized according to the present invention. This information may be provided by an operator or other source, such as upon initial deployment or thereafter, determined through system operation, and/or be compiled as historical information.

A preferred embodiment of the present invention provides for the use of a plurality of channels by ones of the RSs. Accordingly, although the use of a particular channel in a particular antenna beam may be prohibited or restricted as discussed above, an RS may change to another channel for communications, if desired. Using information, such as that shown above, for each such channel in each beam communications may be optimized. It should be appreciated that, as sources of interference may be from uncontrollable sources outside the communication system of the present invention, the ability for RSs to change communications channels may provide advantages in quality of communications beyond optimizing communications.

In a preferred embodiment of the present invention allocation of resources is based on per beam traffic needs, such as may be determined through historical information or initial network configuration parameters. Alternatively, allocation of resources is based on first come (first requiring/requesting communication services) first served, causing later to come (later to require/request communication services) to be blocked on particular antenna beams with respect to simultaneous use of a particular channel.

As described above, that simultaneous use of a channel potentially creates co-channel interference. Depending on factors such as the antenna design and the position of the RS in the antenna beam, the SIR or other signal quality measurement affected by co-channel interference, can vary greatly. In a system using MBA such as in the preferred embodiment of the present invention, beam-to-beam isolation, i.e., the ability of the antenna beams to isolate the signal from other ones of the antenna beams, affects capacity which may be achieved in a cell through the simultaneous use of channels. The graph of FIGURE 6 illustrates the degradation of a simple binary signal with varying SIR, as might be experienced in various antenna beams due to simultaneous use of a particular channel at other

ones of the antenna beams. The results of such interference are much more amplified for high order modulation, such as high level QAM constellations.

Coding, such as that of spread spectrum CDMA, allows error free transmission at much lower SIR. The penalty in providing such error free transmissions in the presence of higher levels of interference is reduced throughput. However, the use of various rate codes may be utilized to maximize throughput for the particular communication attributes experienced in the link.

Solutions of resource allocation according to the present invention allow simultaneous use of 2 antenna beams, but at a reduced throughput. For example, in a CDMA system RSs disposed relatively close to the BS, i.e., low path loss between BS and RS, do not require highly spread codes to achieve low error rate data. In cellular IS-95 systems, E_b/N_o is essentially constant for every user. However, according to a preferred embodiment of the present invention allowing higher E_b/N_o for RSs requiring little power can be traded for a slight rise in E_b/N_o for other users. Having a higher E_b/N_o allows changing spreading codes to achieve higher throughput.

As indicated in the table above, antenna beams 1 and 3 are not fully mutually exclusive antenna beams, i.e., although co-channel interference is present in sufficient magnitude to cause signal qualities to be less than a desired threshold, simultaneous communications may still be established. The use of a reduced rate code provides communications which are more immune to interference than the higher throughput communications possible with the network equipment. For example, simultaneous rate 2/3 convolution codes could be utilized with each of antenna beams 1 and 3, such as may be determined to be acceptable through reference to the above described information, to provide reduced rate simultaneous communications therewith. Such a use of 2 2/3 rate communication channels provides more capacity than the single full rate code which might otherwise be used with antenna beam 1 to the exclusion of antenna beams 2 and 3.

A similar concept may be applied in TDMA systems. RSs which are disposed relatively close to a BS, or otherwise receive a strong signal, may be operated at a reduced power level and/or operated at a higher data rate. As discussed in more detail below, QAM is

an example of modulation where in the same bandwidth, i.e., using a same baud rate, higher levels of modulation may be used to obtain higher data rates.

In the preferred embodiment of the present invention the system operates to automatically optimize simultaneous use of a channel by the affected antenna beams. For example, a database inquiry is performed according to one embodiment of the invention to determine receive energy levels on the primary and interfering antenna beams for both RSs for which simultaneous use of a channel is considered. Thereafter, a determination is made as to whether simultaneous use is desirable, such as through the use of SIR calculations for the user pairs. Such determinations may be carried out for any number of simultaneous uses, such as to three or more RSs simultaneously using a channel by calculating the SIR on each link associated with these RSs.

According to a preferred embodiment of the present invention, the capacity of a cell is optimized by considering the SNR and SIR as well as capacity needs for each RS in the cell. For example, depending upon the SNR available at the RS, the capacity, e.g., the number of bits which may be transmitted to the RS during a defined time slot, may vary greatly. As shown in the table below, an 8 fold capacity increase is obtainable when an extremely high SNR is achievable.

Capacity Increase	QAM Constellation	E_b/N_o @ 10^{-6}	SNR
1	4	10.5	13.5
2	16	15	21.5
4	64	18.5	27
8	256	24	33

Where a very high SNR or SIR is achievable, a high order modulation technique, such as high order modulation available in QAM, phase shift keying (PSK), or quadrature phase shift keying (QPSK), may be used to provide increased capacity. For example, where 33 dB SNR is achievable, an 8 fold capacity increase may be realized using 256 QAM to transmit 8

bits per symbol. Where lower SNR is achievable, such as 20 dB, lower order modulation, such as 4 QAM or even possibly 16 QAM, may be utilized. However, it should be appreciated that such lower order modulation techniques may provide no or little capacity increase.

From the above, it should be appreciated that for any given channel condition, there may be determined an optimum bit density, i.e., modulation/coding combination, that maximizes throughput at a particular acceptable communication quality threshold. For example, a particular preselected BER may be maintained during simultaneous use of a communication channel in various antenna beams through altering modulation or coding techniques to adjust throughput. According to the preferred embodiment of the present invention, determinations of the particular antenna beams at a cell simultaneously utilizing a particular channel are made with respect to optimizing throughput achievable with particular antenna beam combinations, particular available bit densities, and/or quality of service considerations with respect to the RSs.

When simultaneous usage of a resource is prohibited, i.e., a particular channel is already utilized in a particular antenna beam thus blocking the use of this channel in that or another antenna beam, a preferred embodiment of the present invention operates to delay communication, such as where data users are present using packet data. For example, the data packet of a particular user desiring use of a resource for which simultaneous usage is prohibited may be delayed one or more time slots for subsequent rechecking of the particular resource. If the resource becomes available, such as may be determined by checking SIR information or the like, the delayed data packet may be communicated using the previously prohibited resource. In a preferred embodiment, class of service, such as data versus voice communication, is used to determine the particular data packet or packets which get delayed or which experience the most delay etcetera.

In addition to determining allowable simultaneous use of channels within antenna beams of a single cell, a preferred embodiment of the present invention makes determinations regarding inter-cell interference, i.e., interference caused to communications associated with RSs outside the coverage area of a particular cell. Preferably, such

determinations are based on a number of modeling and/or empirical measurements, such as described above with respect to intra-cell interference. Based upon this modeling and/or measurements, mutually exclusive antenna beam pairs between the "home" BS and the BSs surrounding the home BS are identified. The table below shows an example of mutually exclusive antenna beam pairs as determined for the exemplary communication network of FIGURE 8.

Home BS0 Cell 800	BS1 Cell 801	BS2 Cell 802	BS3 Cell 803	BS4 Cell 804	BS5 Cell 805	BS6 Cell 806
800-1	801-1 801-5 801-6					
800-2	801-6	802-2 802-3 802-9 802-10				
800-3		802-8				
800-4			803-3 803-4 803-5 803-11			
. . .						

Shown in FIGURE 8 is a communication network including 7 cells, cell 800 surrounded by cells 801-806. Each cell utilizes multiple antenna beams of the preferred embodiment discussed above. For the example described with respect to the table above, cell 800 will be considered as the "home" cell for inter-cell interference determinations. However, it should be appreciated that any cell of the network may be considered as a "home" cell for this purpose. In fact, a preferred embodiment of the present invention makes determinations of mutually exclusive antenna beam pairs for each cell, thereby identifying each cell a "home" cell with respect to its associated inter-cell interference determinations.

As shown in the table above, there are particular combinations of antenna beams that, when one antenna beam of the combination is in use other ones of the combination will experience interference. For example, if antenna beam 800-1 of cell 800 is transmitting, RSs operating in antenna beams 801-1, 801-5 and 801-6 of cell 801 may receive interference too strong to decode their intended transmissions. Accordingly, it may be desired to avoid

simultaneous use of such antenna beams, such as with respect to a same channel, to avoid communication errors.

With no communication among BSs of the network, a solution would be to apportion the available resources, i.e., time slots or frequencies, among the cell beam pairs according to their traffic needs. For such time slot operations, the stations would preferably utilize a reference clock such as GPS to ensure synchronization among the BSs of the network. For example, in a single channel system, beam 800-1 of cell 800 may share ½ of its time slots with neighboring antenna beams. With centralized timing, the use of beam 800-1 could easily be prevented or avoided when beams which would cause unacceptable interference, such as antenna beams 801-1, 801-5, and/or 801-6, are in use. Without such a clock, frequency division becomes a preferred alternative.

It should be appreciated that time offsets due to differing propagation paths may affect more than a single coincident time slot at a neighboring BS. Accordingly, a preferred embodiment of the present invention may operate to prohibit the use of multiple time slots at ones of the antenna beams and/or make determinations as to distance etcetera in order to determine particular time slots to identify as prohibited with respect to simultaneous use of antenna beams.

Optimization with communication among BSs is conceptually simpler than that described above. For example, if the BS associated with cell 800 knows or can determine what slots are available with respect to particular antenna beams due to internal and external usage, a next slot assignment may be made on a first come first served basis, sharing the available resources between the cells. In providing a fully optimized solution, a preferred embodiment of the present invention allows buffering of several time slots and optimizing time slot assignments over several slots. Accordingly, the system examines all BS/antenna beam/channel pairs and assigns simultaneous usage to those pairs that just exceed a predetermined threshold, such as a SIR threshold, thereby packing the greatest number of uses of the spectrum into the system operation. It should be appreciated that the use of pairs that just exceed the established threshold is preferred as assigning the least interfering pairs to simultaneous usage may result in low interference, but at a cost in capacity.

In a preferred embodiment employing packet data, a packet optimizer is utilized, such as may be embodied in the circuitry and/or programming of the above described BS controller. The packet optimizer of the most preferred embodiment operates to achieve maximum throughput as is possible subject to communication constraints. Specifically, a preferred embodiment of the present invention optimizes throughput of packets based on considerations regarding allowable delay (such as may be packet or service dependent), allowable SIR (i.e., a low available SIR requires reduced data rate), transmit power level (typically related to the distance from the BS to RS, and ideally known for each packet based on the RS it is associated with, subject to noise and interference), forbidden simultaneous beams (reference to information as described above as to antenna beams which may not be transmitted simultaneously or only at a reduced transmission rate), outside interference levels per antenna beam, the number of transmitters available, and/or the like.

Directing attention to FIGURE 7A, BS 101 deployed in cell 102 is shown adapted to provide communication of packet types A and B, such as may be associated with a first radio A and a second radio B (intra-cell reuse N=1/2). It should be appreciated that the configuration of FIGURE 7A provides for communication of packet type A throughout antenna beams 111-110 and 121 and 122 and of packet type B throughout antenna beams 111, 112, and 115-122. Accordingly, both packet types A and B may be communicated throughout antenna beams 111, 112, 115-110, 121, and 122. Accordingly, there are three classes of transmission: A and B simultaneously, A and B simultaneously at a reduced throughput, and only A or B. With random arrivals in all beams, there would frequently be a need to transmit 2 packets simultaneously in a same antenna beam or a pair of adjacent antenna beams.

Having the ability to delay packet transmissions according to the preferred embodiment, the system is adapted to pair simultaneous packets better than their random arrivals to improve or optimize throughput. For example, if packets arrive with equal probability for any of the antenna beams, then there is a 50% probability of blockage, i.e., if a same packet type arrives in a same, or possibly nearby, antenna beam blockage results. Specifically, the case of simultaneous arrival of a pair of A packets (AA) or a pair of B

packets (BB) represent blockage, whereas the simultaneous arrival of one each of an A packet and a B packet (AB or BA) is acceptable for communications. However, if delays are utilized in the simultaneous arrival of a pair (either AA or BB), 2 acceptable pairings may be made (i.e., 2 AB pairs). For example, if a BB packet paring is delayed until an AA packet paring arrives, one of the B packets may be delayed 3 slots and the other 4 slots, along with one of the A packets being delayed 1 slot to form an AB and BA set of packet parings. With equal probability of arrival for both A and B packets and with infinite time delay, all packets may be communicated with optimum efficiency. However, applying constraints, such as an 8 packet allowable delay, optimization may be reduced and/or communication quality may degrade, i.e., an approximately 1% packet drop may be experienced in packet optimization utilizing the above described assumptions.

Directing attention to FIGURE 7B, a block diagram of the operation of a preferred embodiment packet optimizer is shown. Packet optimizer 700, such as may be deployed in the BS controller and/or disposed in the signal path between the BS radios and the BS antennas, is shown. Preferably, packet optimizer 700 includes packet sorter 701 into operational categories, i.e., packets of type A only, packets of type B only, and packets which may be utilized as A or B type. Thereafter, packet optimization module 702 provides sequencing of the packets, preferably utilizing the considerations discussed above, to achieve optimization. The optimized pairings and/or sequences of packets are output from packet optimizer 700 for use by other BS equipment, such as may be provided to air interface converters for ultimate provision to BS radios.

In a preferred embodiment, time division duplexing (TDD) is used with frequency reuse to provide increased communication capacity in the cell. One advantage of TDD systems is that a single switch matrix may be readily utilized in coupling the radios and MBA. Directing attention to FIGURE 15, a preferred embodiment of the circuitry of a TDD system providing for multichannel multibeam wireless communications is shown. Specifically multiple (K) BS radios, radios 1501-1502, are selectively coupled to the antenna beams of a multiple beam antenna. Accordingly in the preferred embodiment of FIGURE 15

switch 1503 is disposed in the signal paths between radios 1501-1502 and antennas 211-222 and provides selectable communication between any combination thereof.

It should be appreciated that, for TDD systems having frequency reuse within a cell, a difficulty occurs when the packet sizes of forward and reverse links are not the same for each antenna beam, i.e., reuse of the channel. This difficulty is caused because the forward link of one channel may overlap with the reverse link of a reuse of that channel. This situation is illustrated in FIGURE 16. Shown in FIGURE 16 are 2 RF channels A and B (A and B are assumed to be at the same frequency) serving different angular areas (sectors) of a cell. The B channel in this situation is overpowered by leakage from the A channel antenna in the overlap region.

Accordingly, a preferred embodiment of the present invention, wherein TDD is employed, operates to balance the traffic among the antenna beams. For example, where an adjustment of a forward or reverse link frame for one channel is also made for other channels where overlap would be a problem. Such balancing may utilize the above mentioned variable sector boundaries in order to balance the traffic on the channels in order to make it possible to provide the desired communications with the adjusted TDD frames. Additionally or alternatively, the present invention may operate to delay temporarily traffic to eliminate the overlap. Also additionally or alternatively the present invention may employ interference cancellers during he overlap time period to minimize the impact of the overlap.

It should be appreciated that the systems of the present invention may utilize diversity reception and/or transmission at either or both of the BSs and RSs. Such diversity may be provided due to an independent signal path associated with polarization diversity, space diversity, angle diversity, or any combination thereof. The use of such diversity may be relied upon to provide higher signal qualities and, thus, more capacity and/or higher throughput.

Remote Site Smart Antennas

As discussed above, there are several reasons for using smart antennas at the customer site in addition to the base site. Smart antennas provide interference reduction due to their controllable narrow beamwidth and controllable direction. In addition, if a user is experiencing an unacceptable amount of interference, the user can be directed to another base site. This is shown in FIGURE 17 in which system 1700 shows two base sites, 1701 and 1702, in communication with customer premise antenna 1703. Remote antenna 1703 has its beamwidth directed at base site 1701 as shown by the field 1701A. However, after interference is detected from some source or if there is excessive loading at base site 1701, or for any other reason, the antenna at customer premise site 1700 changes its beam size and/or its direction so that CPE 1703 focuses its beam as shown in 1702A to communicate with base site 1702.

Turning now to FIGURE 18, there is shown a new base site 1801 which is either added to the system or which begins for some reason to impact the coverage areas of base sites 1701 and 1702. This impact from base site 1801 can be from a number of sources, including by way of example, a change in atmospheric conditions, a change in construction of buildings in the path, a change in power, or perhaps a movement of customer 1703 to a slightly different location. Note that with respect to FIGURE 18, beam 1801A is in a different direction than either beam 1701A or 1702A and has a different configuration. Thus, not only is the direction of the antenna changed, but the width of the beam can be changed, as necessary.

FIGURE 19 shows one configuration for the smart customer premise equipment. Receiver controller 1902 gathers information on each of the beams 19-1 through 19-6 including quality and loading information sent from the base site over the air and directs the data from the subscriber's LAN through a specified beam to the selected base site. The system can be configured to switch beams on a per session basis (minutes or hours) or a per time slot basis (milliseconds) One example of how to direct beams of an antenna for width and/or direction is shown in U.S. Patent 5,889,494 issued March 30, 1999 entitled "Antenna Deployment Sector Cell Shaping System and Method", which is hereby incorporated by reference herein. As shown in FIGURE 19, 1901 is a switch and 1902 controls the switch

and receives signals from the base sites. The controller could be, for example, a micro processor and could have memory to execute the procedure for determining antenna direction on both the Rx and Tx paths.

The flowchart of FIGURE 20 shows the operation of one possible system. Flowchart 2000 can be expanded to include additional information obtained from the base site, such as a request to change to another base site based on loading, or a request to change to a different beam to mitigate interference.

As shown in FIGURE 20, upon power up, box 2001, the system obtains quality information on the antenna as shown in box 2002. If the quality information on the antenna box 2003 is not good, then the system is instructed to switch to the next antenna, box 2004. This antenna can actually be a combination of antennas 19-1 through 19-6 shown in FIGURE 19, configured such that they physically point in a different direction or have a different radiation field as discussed above. Once the new direction or new combination is decided upon, boxes 2002 and 2003 and 2004 are repeated until it is decided upon which direction the antennas should point or which configuration the field should take. Note that this loop of 2002, 2003 and 2004 can be repeated at whatever time intervals as are necessary to achieve a desired result. Note also that the selection of a direction and/or width of a beam can be made by following a pre-established procedure (which can be modified from time to time) or by information cooperatively generated between the base station and the CPE. The system can operate in several ways, for example:

1. There can be means where RS simply "homes in" on a BS for example, tuning to a carrier;
2. There can be means where BS transmits a unique beacon with information, e.g., "I'm full", "I'm half full", "I'm out of service", "I'm busy, go to BS#", etc.;
3. The BS and RS's can negotiate;
4. The central controller can select BS-RS path for optimum network performance.

In combination with loop 2002, 2003 and 2004, the system then goes on to select the base site with the highest quality via box 2005. This selection loop consists of checking as to whether service is available at a particular site, box 2006; checking all the sites, box 2007; and then selecting another site, box 2008. Note that box 2008 can either be a sequential selection of the next base site, or the "next" base site can be selectively programmed. This program could rely on a memory with respect to different base sites for different times or for other patterns that are known so that the selection of the base site at any particular time depends upon particular circumstances including weather or other conditions. For systems that are designed to make selections on a fast basis, the selection process could very well entail having residual memory or other information such that the decision is not entirely random but is based upon a preestablished set of factors. Some of these factors could be recent past history which have been taken into account and can be set within box 2008. In addition, information can come in from external sources, either by RF or by direct telecommunication connection, or even via the internet, so that the next base site selection is tested based upon factors internal to the customer's system, as well as factors that are external and communicated thereto.

Once these factors have been determined to be the best fit, boxes 2009 and 2010, combine to select the best cell site and to transmit that data to the cell site, either via phone lines, RF, radiation, or a combination of the above. Of course, since box 2008 can receive information from external sources, the selection of cell sites can be an interactive process between the base station and the remote site or between a controller system remotely located or even incorporating cell sites that are not active in this communication, but which have an interest in keeping interference within a certain specified range.

When the smart CPE antenna is not integrated into a manufacturer's equipment, a method for pointing the CPE antenna at the proper base site must exist. The following describes one method for performing the pointing of the CPE antenna.

Each base station, BS, could transmit a unique code or frequency to all nearby CPEs. The CPE has a narrow-beam antenna that must be pointed to a primary base site. As

discussed, the CPE antenna may transmit to an alternate base site. Thus, the CPE system must collect information regarding the "location" of multiple base sites.

The CPE contains a receiver and a code detector, perhaps located in box 1902 (FIGURE 19), that can measure signal strength (box 2003) once a code is detected. Controller 1902 (FIGURE 19) can then steer or rotate the antenna as desired. Controller 1901 may or may not communicate with the other CPE radio equipment. Upon startup in an autonomous mode, the controller may check to see if the last pointing angle still contains the base site with the strongest signal strength by scanning all known codes for the base sites for the area. More advanced control may require communication with the CPE radio.

On installation, for example, the user might key into the smart CPE the zip code of the remote site. All candidate base sites in this region would be mapped to this code controlled, for example, by box 2008. This allows a nationwide (worldwide) network with individually coded base sites, for example XXXXXX.YYYYYY where XXXXXX is the postal code and YYYYYY is the base site identification code. This reduces the search time upon startup. Other systems could be used, including an omni-directional RF signal containing certain code information sent from different base sites. Alternatively, each city may independently use one of 100 codes to identify base sites in that region. The codes can be reused some distance away where there is no ambiguity between base sites.

It is preferred, but not necessary, that the portion of the RF spectrum used for beam pointing be in a separate frequency range near the edge of the band utilized by the RF communication devices. If this is impractical, a low level high spread spectrum signal would be acceptable.

Another alternative is to build a more complex receiver that locks to the system air interface. In this case, the beacon is contained in the air interface (e.g. the IS-95 pilot signal) so a separate transmitter is not needed.

FIGURE 21 shows the base system when a separate transmitter 2102-1 to 2102-3 is used at the base system to send codes, or other control information, via transmitter control 2101 and antenna 2103. A smart antenna (while shown) need not be used at the base site, if desired.

FIGURE 22 shows one example of CPE system 2200 where switch 2201 prevent system 2200 from transmitting data while the system is receiving and/or transmitting control information via control 2202, 2204 so as to direct the antenna toward the proper base site. Once the base site is found, switch 2301 is changed to route the RF signal to CPE modem 2203. Smart CPE system 2200 may also contain up converters, down converters, filters and amplifiers. This permits all modems to be identical. RF channel selection is commanded preferably in software, as discussed with respect to FIGURE 20. The direction of transmission thus changes for system 2200 according to the RF band, power level requirements, antenna gain requirements for all various air interfaces and applications. Code receiver 2204 can be a code or a signal strength Rx.

The CPE may have a GPS system integrated into it allowing the location and pointing directions of the antenna to be known. Once the location and pointing direction of the CPE are known, the base site would sent out signals which would directed the CPE towards it. As discussed, the CPE direction may either be through the use of switched beams or by adjusting phases to steer a beam or by mechanically steering (such as a motor, not shown) an antenna. The information used for determining CPE antenna direction can come from base sites, other CPE sites and/or information received independently from other sources, such as, for example, interference maps downloaded to the CPE, its own interference calculations, memory of past events, etc. BS can send GPS information to RS. Since BS and RS locations are known, the angle can be determined.

Note that "direction" as used herein in used in a broad sense. The aptitude and phase applied to elements of an antenna to maximize transmission may cause a distorted wave front with no true single direction. In addition, the CPE antenna can actually send a signal which bounces off one or more buildings (or other objects) between the CPE and a base station.

Note that while the Rx and Tx are usually directed to the same base station, this need not be the case. For example, the CPE could be receiving signals from one base site while transmitting simultaneously to another base site, either over the same frequency or a different frequency.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

WHAT IS CLAIMED IS:

1. An antenna system for use at a wireless site remote from a base station site, said system comprising:

an antenna at said remote site having at least one controllable beam direction; and

means for adjusting said beam direction of said remote site antenna dependent upon desired transmission characteristics between said remote site and a particular base site.

2. The system of claim 1 wherein said adjusting is controlled in part by the establishment of a desired base site as the base site to and from which transmission is desired.

3. The system of claim 1 wherein said particular base site is selected from the list including:

a preferred list;

an interactive communication between one or more base sites and said remote site;

signal strength detection;

relative loading, time of day, reception of a special signal form a base station; and

responsive to a central controller.

4. The system of claim 1 wherein said antenna further includes:

a narrow beam antenna system.

5. The system of claim 4 wherein said narrow beam antenna system includes a plurality of antennas, the radiation pattern achieved by selectively switching the beams of said plurality of antennas.

6. The system of claim 4 wherein said narrow beam antenna system includes a plurality of antennas, the radiation pattern achieved by adjusting the relative phase among said plurality of antennas.

7. The system of claim 1 wherein said beam direction is controlled by physically rotating one or more antennas.

8. The system of claim 1 wherein said remote system includes:

means for processing information relative to a plurality of base sites.

9. The system of claim 8 wherein said processing means is interactive with respect to one or more of said base sites.

10. The system of claim 8 wherein said processing means includes using information stored within said remote site.

11. The system of claim 8 wherein said processing means includes interchanging information with other transmission sites.

12. The system of claim 8 wherein said processing means includes obtaining information from sources other than said base sites.

13. The system of claim 1 wherein said system includes:

means for separating the transmission direction from the received direction.

14. The system of claim 13 wherein said separating means includes using beam switching at said remote site.

15. A method for controlling wireless communications at a site remote with respect to a base site, said method comprising the steps of:

establishing at said remote site an antenna having a controllable beam direction; and

adjusting said beam direction dependent upon desired transmission characteristics to and from said remote site from a particular base site.

16. The method of claim 15 wherein said adjusting step includes the step of:

establishing a desired base site as the base site to and from which transmission is from said remote site.

17. The method of claim 15 wherein said antenna is a narrow beam antenna system.

18. The method of claim 17 wherein said narrow beam antenna system includes the step of selectively switching the beams of a plurality of antennas.

19. The method of claim 17 wherein said narrow beam antenna system includes the step of adjusting the relative phase among a plurality of antennas.

20. The method of claim 15 wherein said adjusting step includes the step of:

physically rotating one or more antennas.

21. The method of claim 15 further including the step of:

processing information at said remote site relative to a plurality of base sites.

22. The method of claim 21 wherein said last-mentioned processing step is interactive with respect to one or more of said base sites.

23. The method of claim 21 wherein said last-mentioned processing step includes using information stored within said remote site.

24. The method of claim 21 wherein said last-mentioned processing step includes interchanging information with other transmission sites.

25. The method of claim 21 wherein said last-mentioned step includes obtaining information from sources other than said base sites.

26. The method of claim 15 further including the step of:

separating the transmission direction from the received direction.

27. The method of claim 26 wherein said separating step includes using beam switching at said remote site.

28. A wireless system in which a plurality of base stations are in communication with a plurality of remote stations via antenna systems located at said base and remote stations, said system comprising:

means at of least one remote station for determining at particular times which base station is a preferred base station at such particular time for exchanging communication with that remote station; and

means cooperative with at least one of said base stations and dependent in part upon said determining means for directionally changing the radiation pattern of the antenna system at said remote station.

29. The system of claim 28 wherein said cooperation is selected from the following

homing in on a base site;

recovering signals from a base site;

receiving instructions from a base site;

receiving status information from a base site;

negotiation with the base site;

communications with a controller; and

unavailability of a particular BS.

30. The system of claim 28 wherein said radiation pattern change includes both the transmit and the receive patterns.

31. The system of claim 30 where said pattern change can be different for the transmit and receive patterns of a remote station.

32. The system of claim 28 wherein said determining means includes:

means for interacting with data provided external to said remote station.

33. The system of claim 32 wherein said external provided data can come from the list consisting of:

other remote stations, a plurality of base sites, past history at one or more remote sites, data stored in memory at said remote site, data downloaded from sources external to said wireless system, data received from GPS systems.

34. A method of operating a wireless system in which a plurality of base stations are in communication with a plurality of remote stations via antenna systems located at said base and remote stations, said method comprising the steps of:

determining at of least one said remote station at particular times which base station is a preferred base station at such particular time for exchanging communication with said at least one remote station; and

directionally changing the radiation pattern of the antenna system at said at least one remote station in cooperation with at least one of said base stations and dependent in part upon said determining step.

35. The method of claim 34 wherein said directional change of said radiation pattern includes changing the transmit and/or the receive patterns.

36. The method of claim 35 where said directional change can be different for the transmit and receive patterns of a remote station.

37. The method of claim 34 wherein said determining step includes the step of:

interacting with data provided external to said remote station.

38. The method of claim 37 wherein sand external provided data can come from the list consisting of:

other remote stations, a plurality of base sites, past history at one or more remote sites, data stored in memory at said remote site, data downloaded from sources external to said wireless system, or data received from GPS systems.

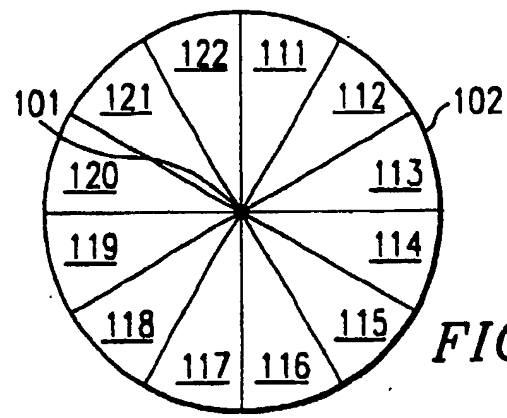


FIG. 1

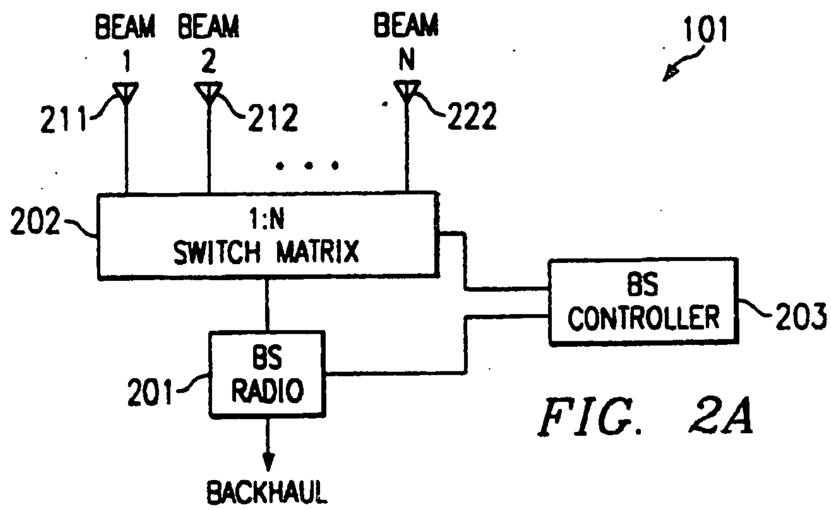
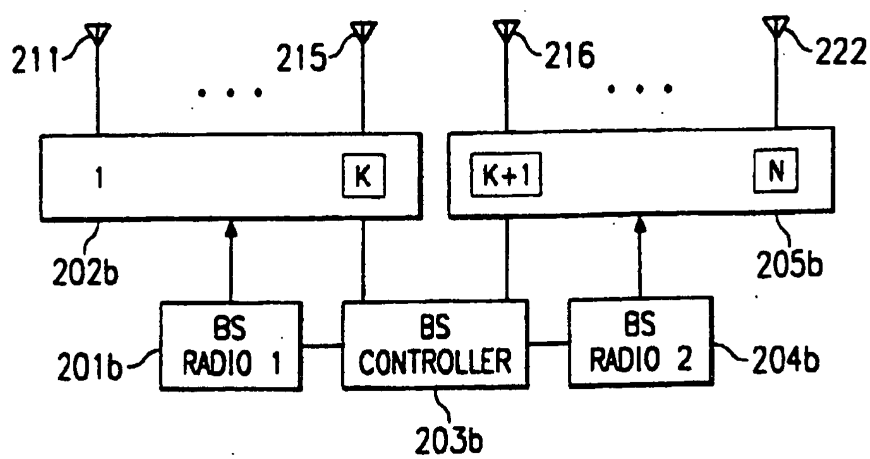


FIG. 2A

FIG. 2B



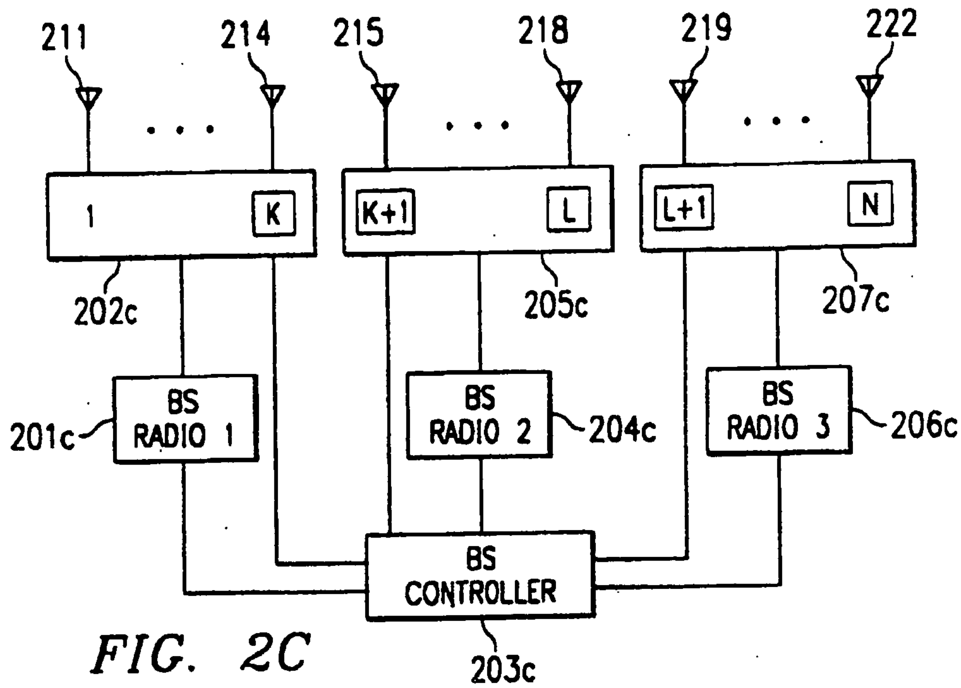

211
214
215
218
219
222
1
K
K+1
L
L+1
N
202c
205c
207c
BS RADIO 1
201c
BS RADIO 2
204c
BS RADIO 3
206c
BS CONTROLLER
203c

FIG. 2C

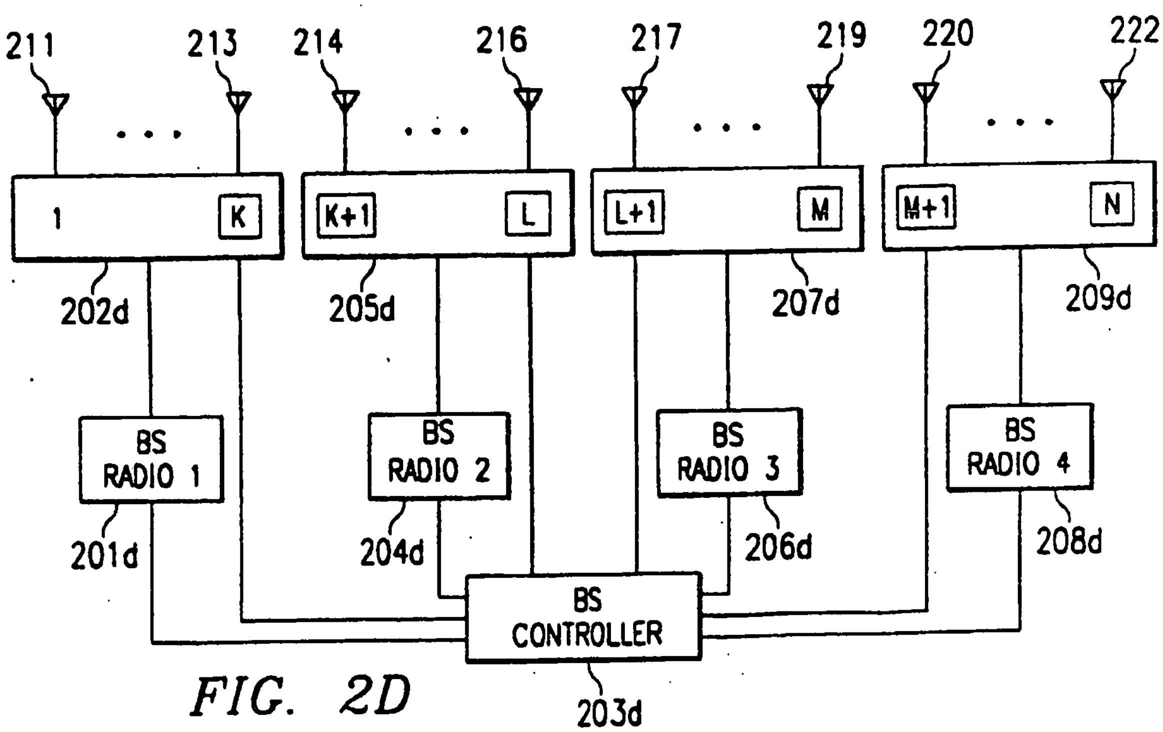

211
213
214
216
217
219
220
222
1
K
K+1
L
L+1
M
M+1
N
202d
205d
207d
209d
BS RADIO 1
BS RADIO 2
BS RADIO 3
BS RADIO 4
201d
204d
206d
208d
BS CONTROLLER
203d

FIG. 2D

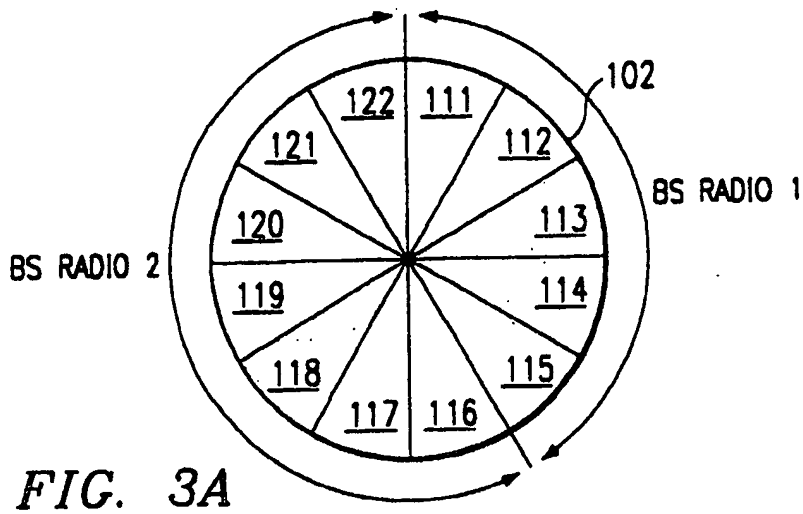


FIG. 3A

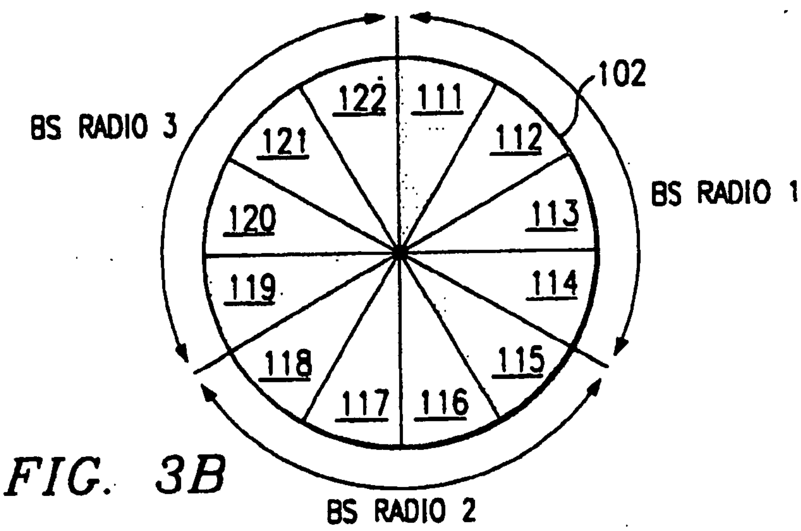


FIG. 3B

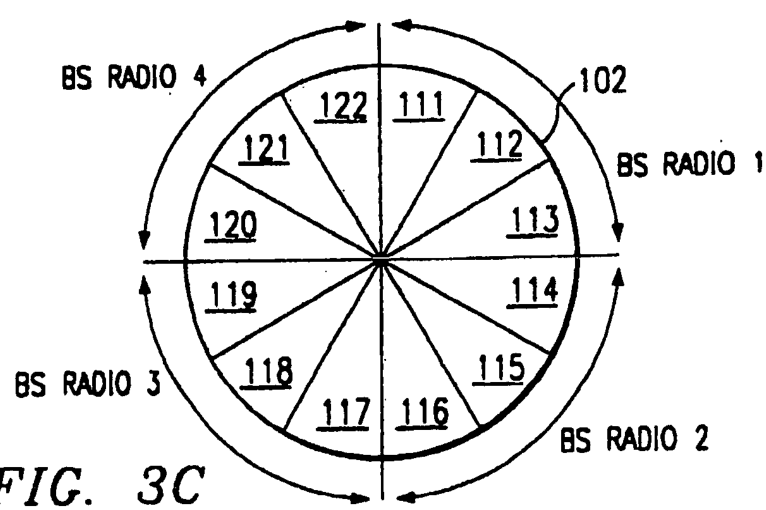


FIG. 3C

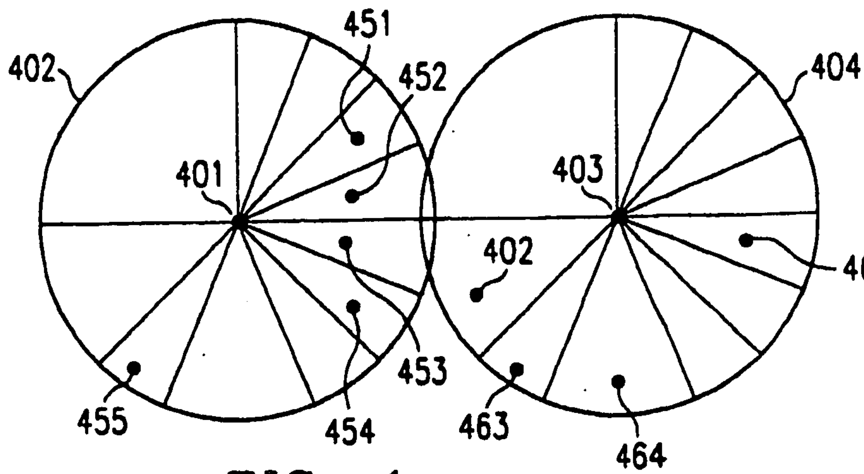


FIG. 4

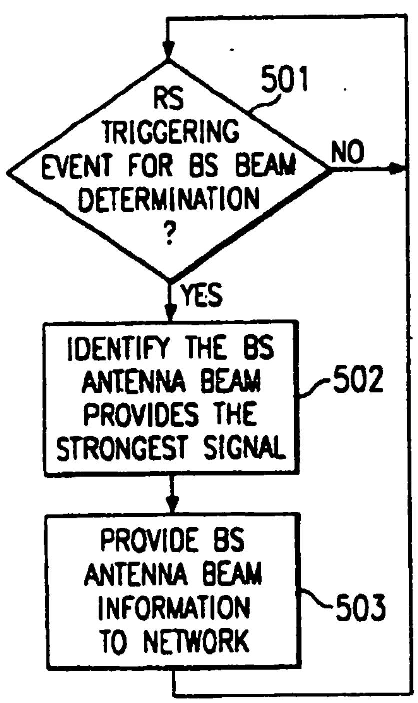


FIG. 5A

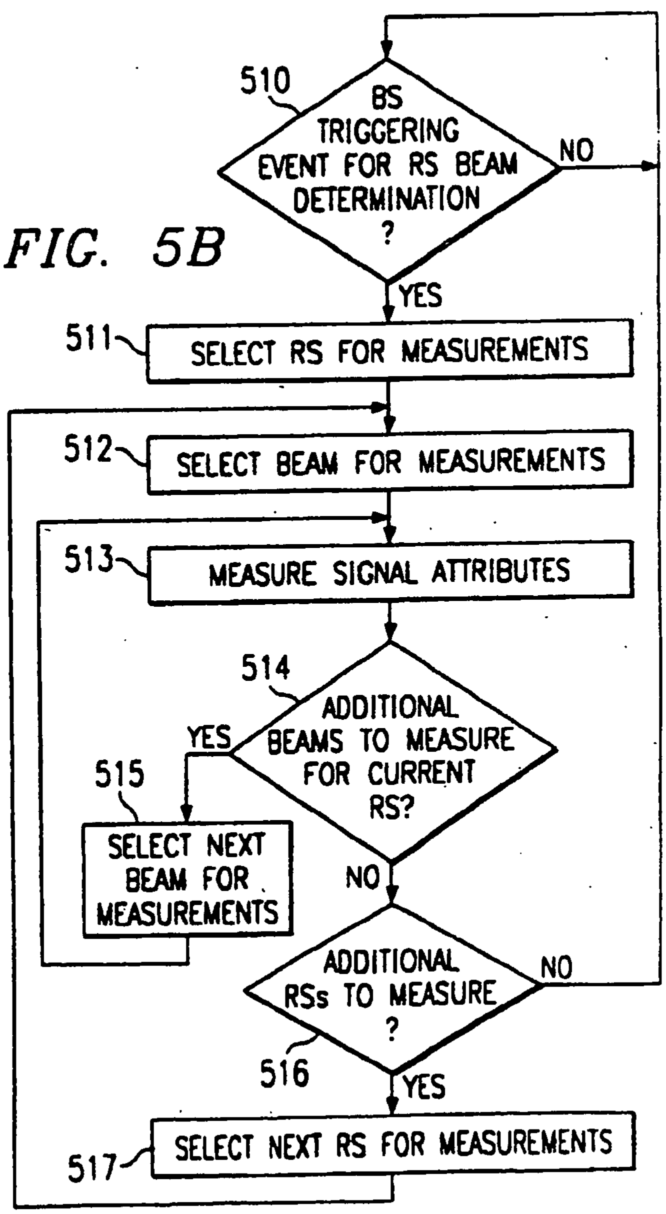
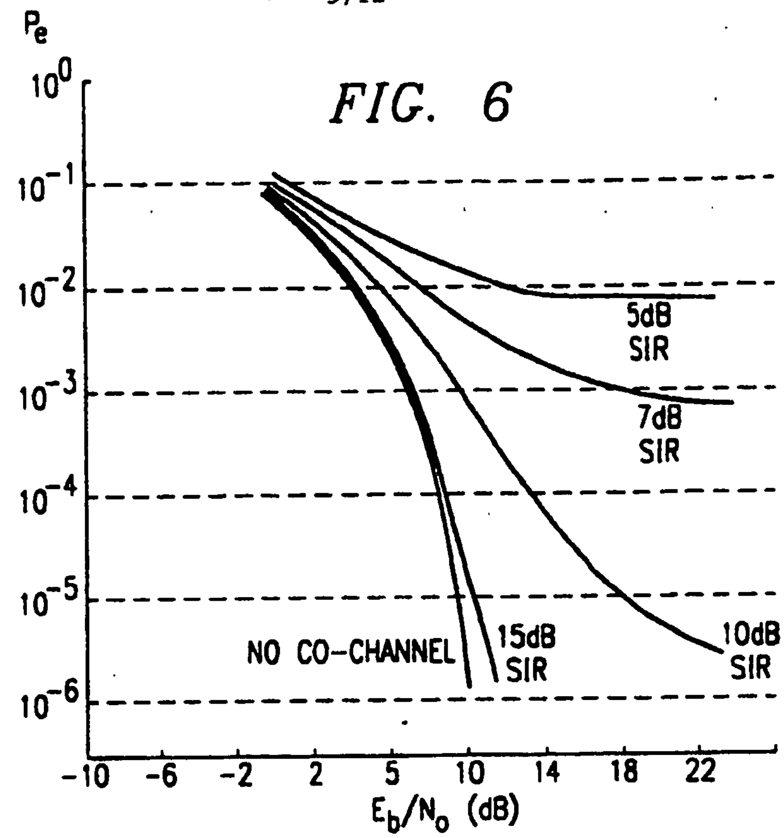
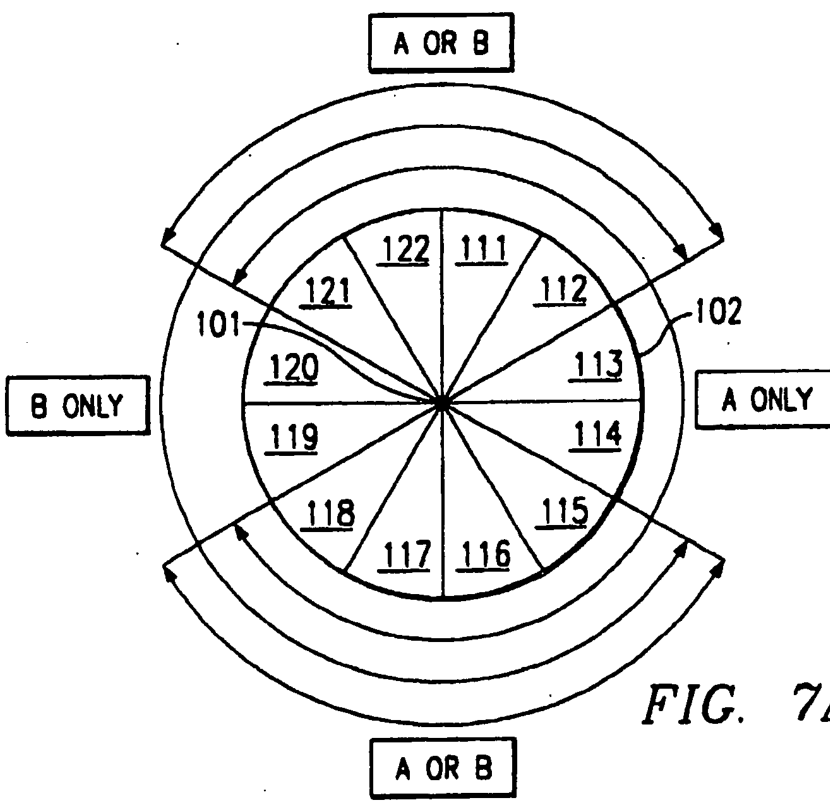


FIG. 5B



P_e
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
5dB SIR
7dB SIR
10dB SIR
15dB SIR
NO CO-CHANNEL
-10
-6
-2
2
5
10
14
18
22
E_b/N_o (dB)

FIG. 6



A OR B
B ONLY
A ONLY
A OR B
101
102
111
112
113
114
115
116
117
118
119
120
121
122

FIG. 7A

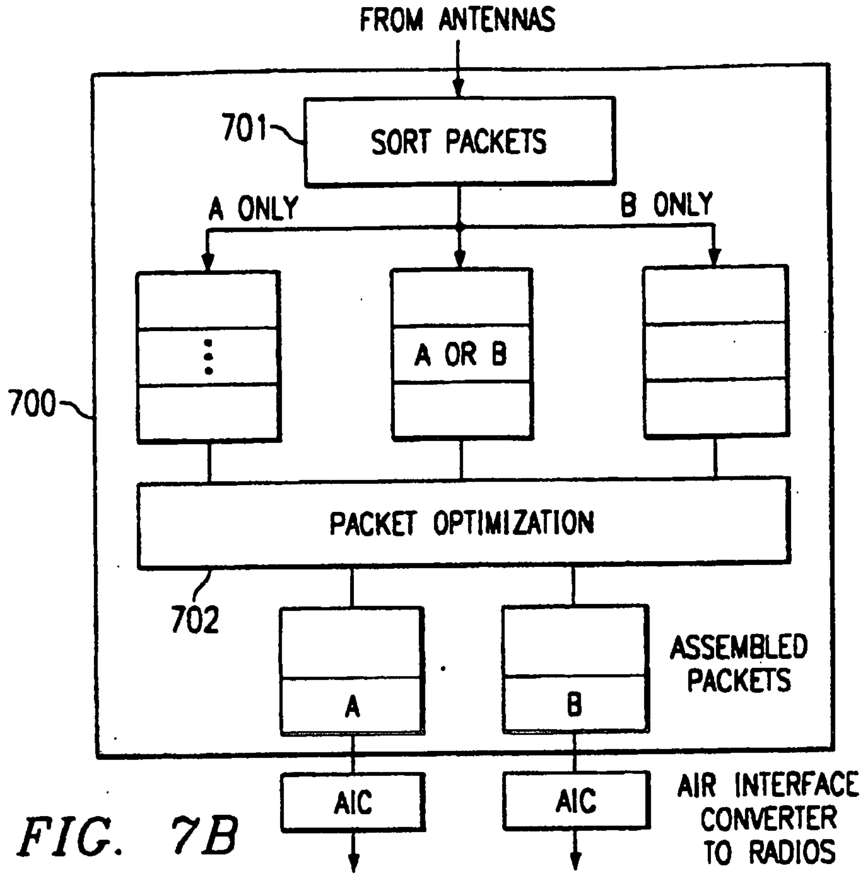


FIG. 7B

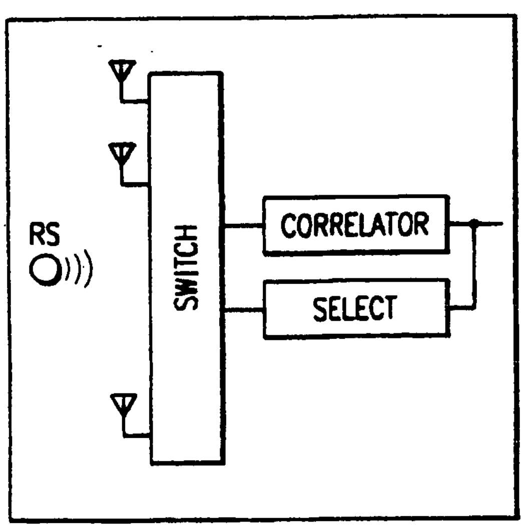


FIG. 9

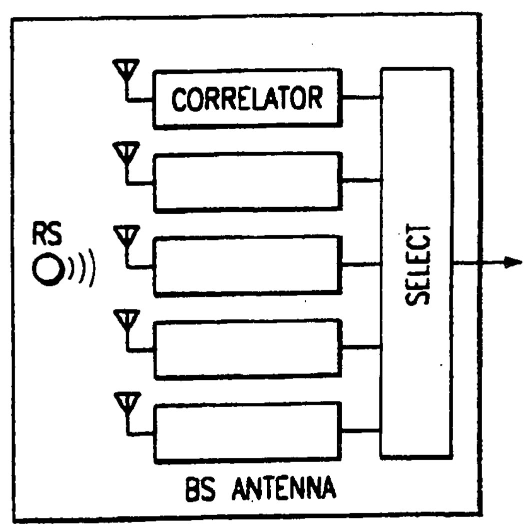
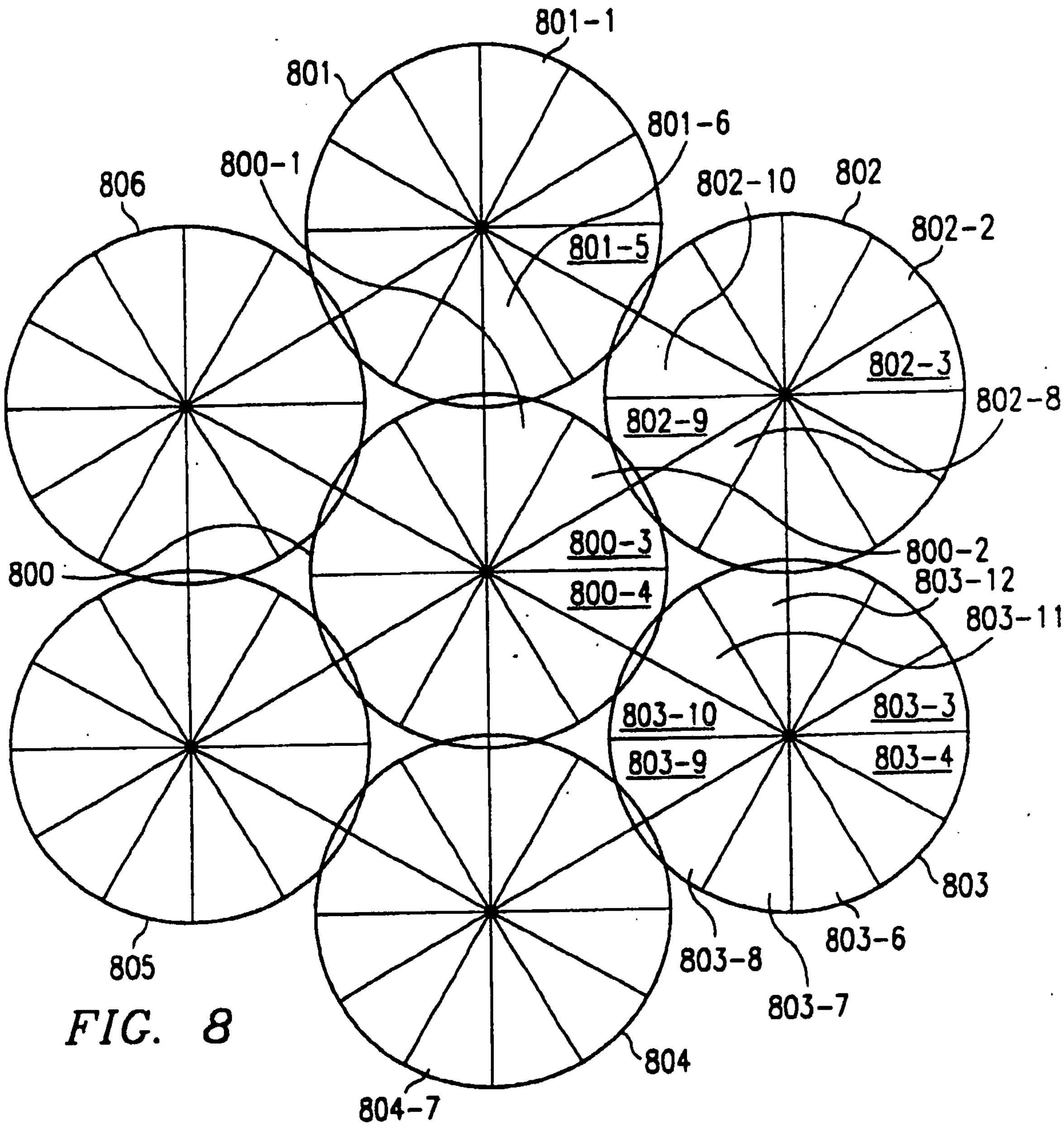


FIG. 10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801-6
800-1
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800
800-4
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803-6
803-7
804
804-7

FIG. 8

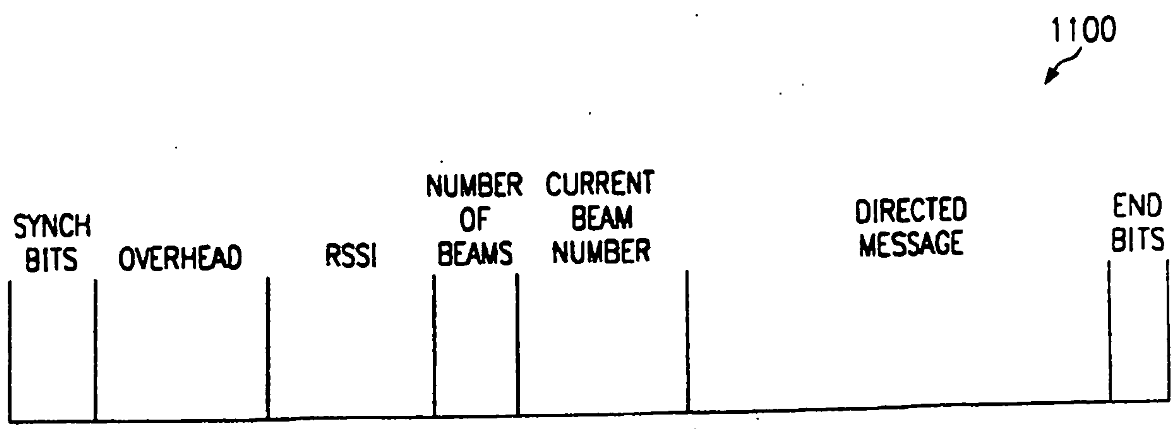

1100
SYNCH BITS
OVERHEAD
RSSI
NUMBER OF BEAMS
CURRENT BEAM NUMBER
DIRECTED MESSAGE
END BITS

FIG. 11

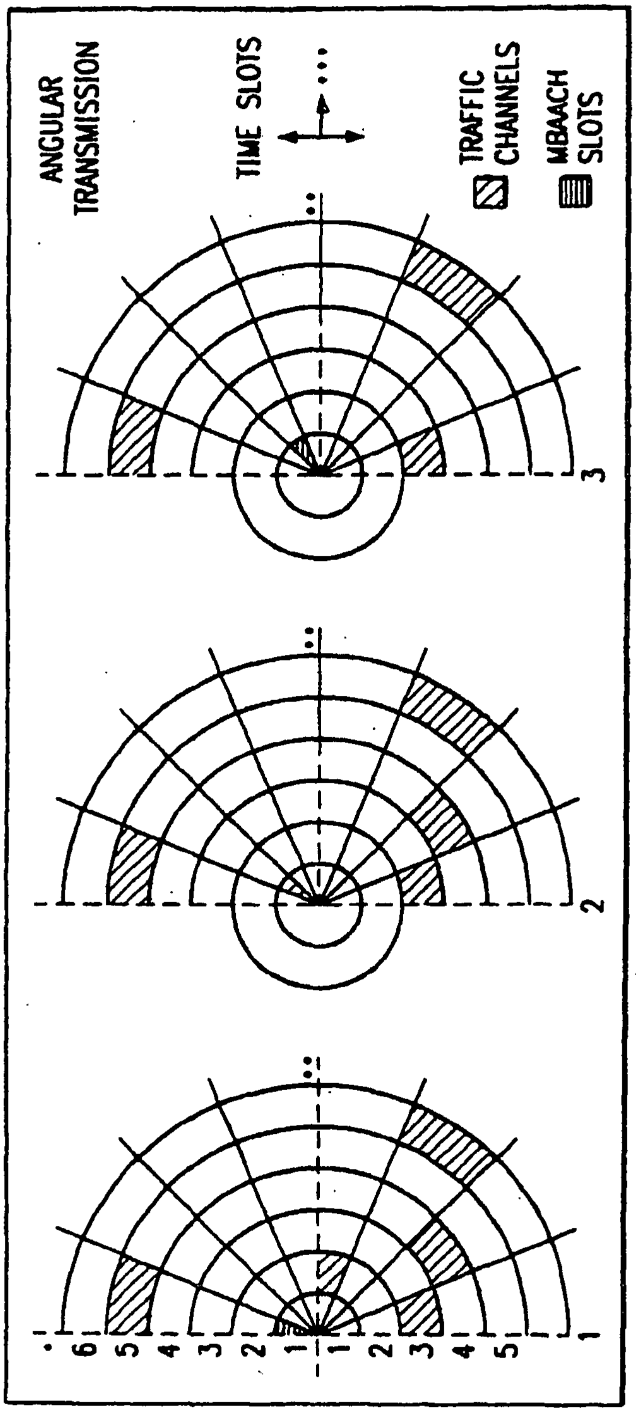

ANGULAR TRANSMISSION
TIME SLOTS
TRAFFIC CHANNELS
MBAACH SLOTS
6 5 4 3 2 1 1 2 3 4 5
1
2
3

FIG. 12

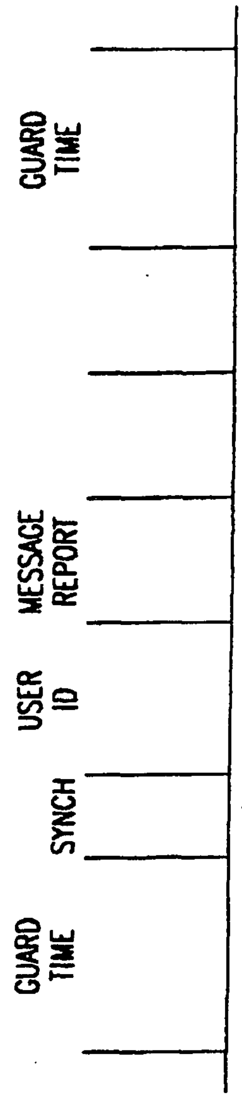

GUARD TIME
SYNCH
USER ID
MESSAGE REPORT
GUARD TIME

FIG. 13

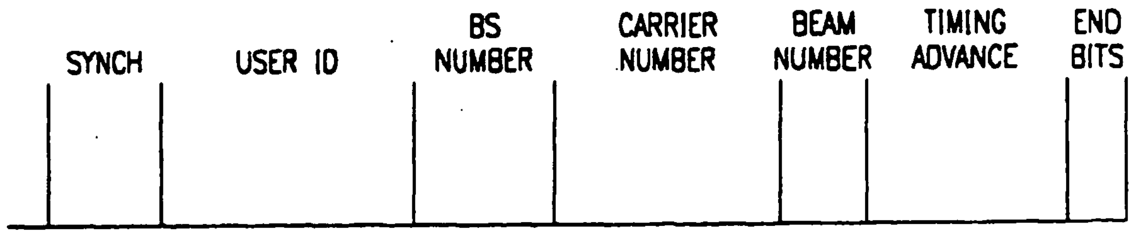


FIG. 14

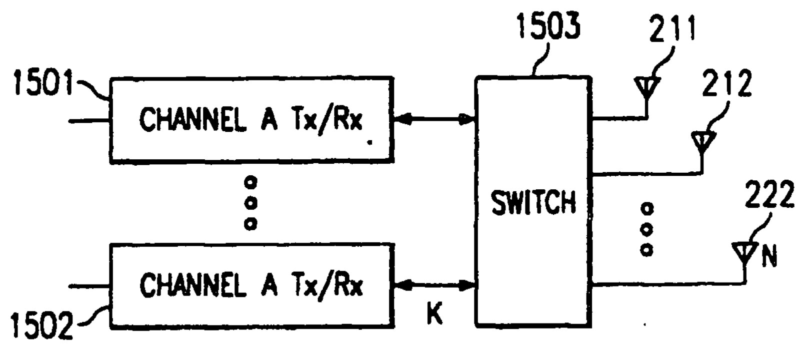


FIG. 15

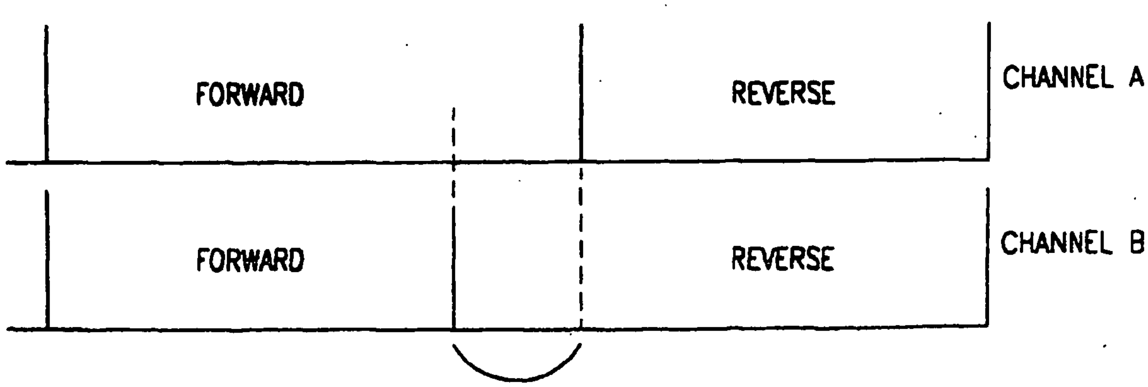


FIG. 16

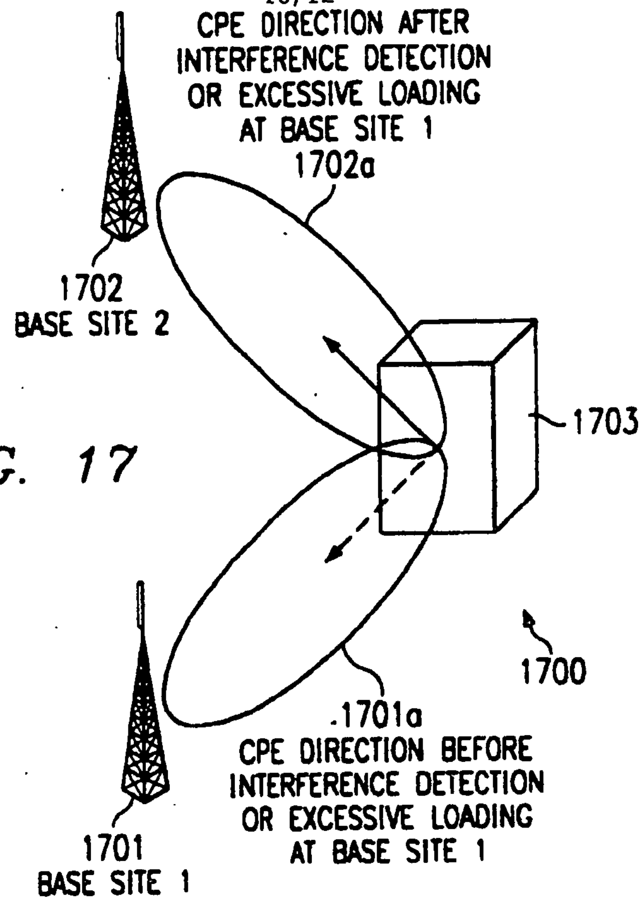

CPE DIRECTION AFTER
INTERFERENCE DETECTION
OR EXCESSIVE LOADING
AT BASE SITE 1
1702a
1702
BASE SITE 2
1703
1700
1701a
CPE DIRECTION BEFORE
INTERFERENCE DETECTION
OR EXCESSIVE LOADING
AT BASE SITE 1
1701
BASE SITE 1

FIG. 17

FIG. 18

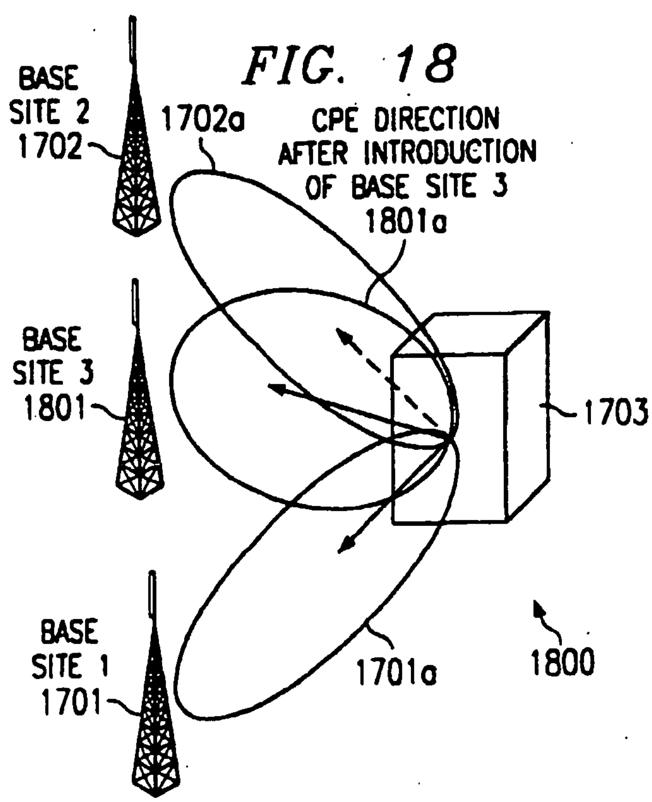

BASE
SITE 2
1702
1702a
CPE DIRECTION
AFTER INTRODUCTION
OF BASE SITE 3
1801a
BASE
SITE 3
1801
1703
BASE
SITE 1
1701
1701a
1800

FIG. 19

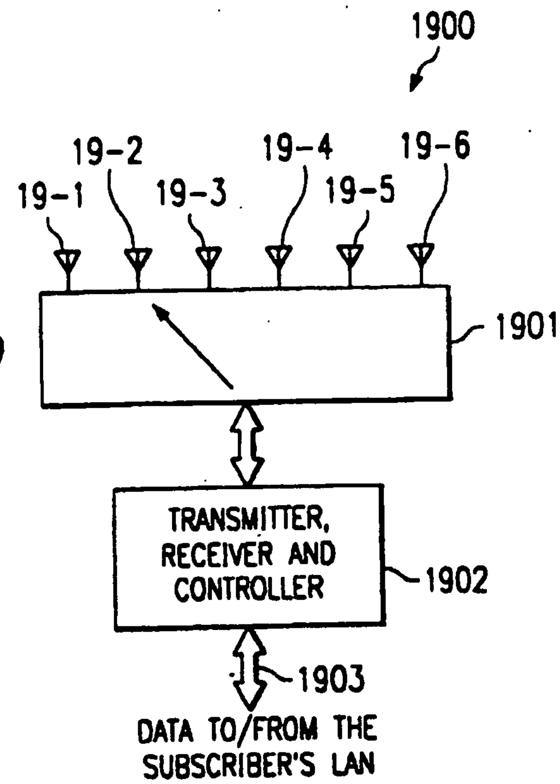


FIG. 21

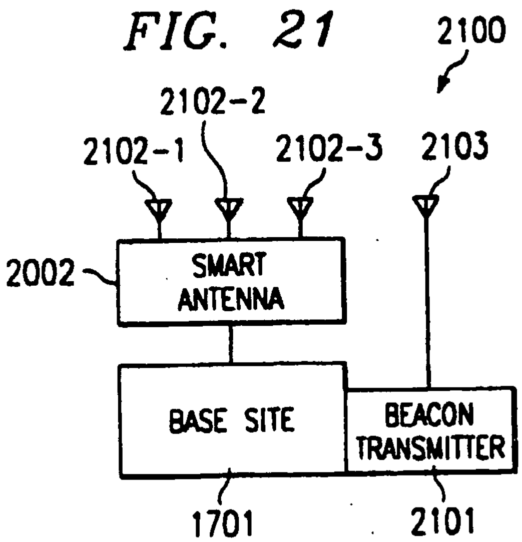


FIG. 22

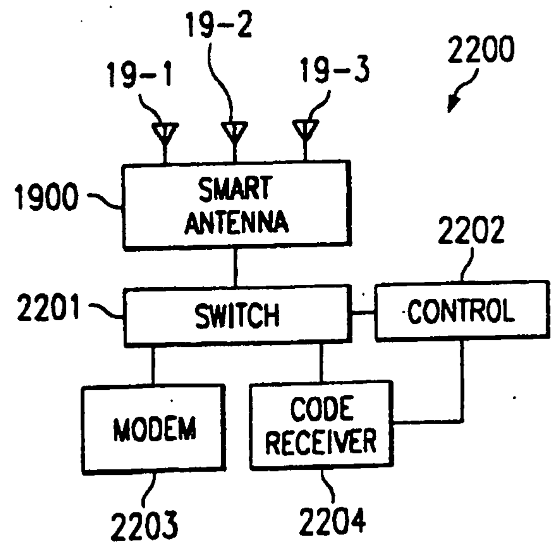
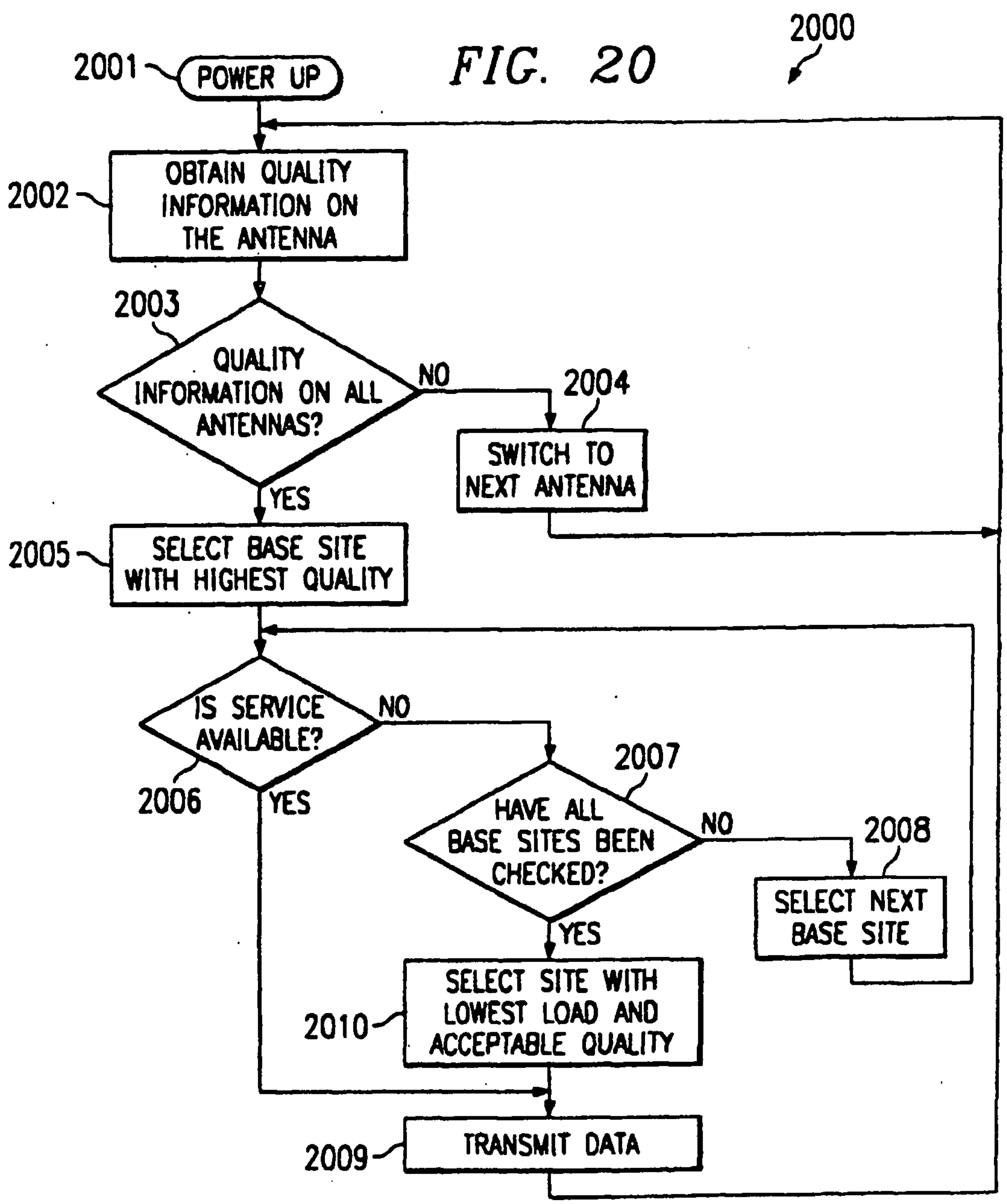


FIG. 20


2000
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POWER UP
2002
OBTAIN QUALITY INFORMATION ON THE ANTENNA
2003
QUALITY INFORMATION ON ALL ANTENNAS?
NO
2004
SWITCH TO NEXT ANTENNA
YES
2005
SELECT BASE SITE WITH HIGHEST QUALITY
IS SERVICE AVAILABLE?
NO
2006
YES
2007
HAVE ALL BASE SITES BEEN CHECKED?
NO
2008
SELECT NEXT BASE SITE
YES
2010
SELECT SITE WITH LOWEST LOAD AND ACCEPTABLE QUALITY
2009
TRANSMIT DATA

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/31403

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01Q1/24 H01Q3/26 H01Q3/24 H01Q3/02 H04Q7/38 H04Q7/36

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01Q H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 540 387 A (ALCATEL) 5 May 1993 (1993-05-05)	1-4,6, 13, 15-17,19
Y	column 3, line 10 -column 4, line 19; figures 1-3B	5,7-12, 14,18, 20-38
X	EP 0 649 227 A (ALCATEL SEL) 19 April 1995 (1995-04-19)	1-4,6, 13, 15-17,19
Y	the whole document	5,7-12, 14,18, 20-38

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 March 2001	21/03/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Angrabeit, F

2

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	ESTABROOK P ET AL: "A 20/30 GHZ PERSONAL ACCESS SATELLITE SYSTEM DESIGN" INTERNATIONAL CONFERENCE ON COMMUNICATIONS, US, NEW YORK, IEEE, vol. -, 11 June 1989 (1989-06-11), pages 216-222, XP000075461 page 219, paragraph 3. -page 220; figures 4-7	5,7,18, 20
Y	US 5 949 369 A (BRADLEY ET AL.) 7 September 1999 (1999-09-07) abstract column 1, line 29 -column 2, line 13 column 5, line 56 -column 8, line 7 column 9, line 29 -column 15, line 29; figures 6-19	8-12,14, 21-38
Y	US 5 650 788 A (JHA) 22 July 1997 (1997-07-22) column 2, line 48 -column 3, line 19; figures 1-33	8-12,14, 21-38
A	WO 99 16221 A (INTEL) 1 April 1999 (1999-04-01) abstract; figures 1-9	1,3,15, 28,34
A	US 5 893 033 A (KESKITALO ET AL.) 6 April 1999 (1999-04-06) abstract column 4, line 51 -column 5, line 30; figures 1-13	1,8-12, 15,21-38

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Information on patent family members

International Application No
PCT/US 00/31403

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